

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF
MORROW POINT DAM SPILLWAY, OUTLET WORKS, AND POWERPLANT
TAILRACE
COLORADO RIVER STORAGE PROJECT
CURECANTI UNIT, COLORADO

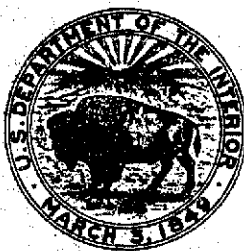
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Hydraulics Branch
DIVISION OF RESEARCH



OFFICE OF CHIEF ENGINEER
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MORROW POINT DAM & POWER PLANT
COLORADO RIVER STORAGE PROJECT

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ABSTRACT

The preliminary design of an overflow spillway at the crest of the dam and a slide-gate-controlled outlet works near the dam base was abandoned because of undesirable flow conditions in the stilling basin resulting from high velocity efflux from the outlet works. An alternate design, consisting of four fixed-wheel gate-controlled outlets near the dam crest and a small outlet works near the base, was recommended following several modifications. A 1:24 scale model was used in developing the design of the spillway and to determine the hydraulic operating characteristics of the recommended freefall orifice-type spillway, slide-gate controlled outlet works, and tailrace channels of the underground powerplant. Comprehensive data were obtained concerning pressure distribution in the spillway conduits and bellmouth entrances, on the stilling basin floor, and on the stilling basin weir. Minor modifications were made to the topography in the tailrace area to improve flow conditions during large spillway discharges. The stability of riprap protection was determined, and tests were made concerning movement of material in the stilling pool. Operating characteristics of all features of the recommended design were observed.

DESCRIPTORS-- *arch dams/ *spillways/ *outlet works/ *free fall/ *model tests/ hydraulic models/ manometers/ orifices/ tailrace/ water pressures/ weirs/ instrumentation/ piezometers/ pressure measuring equip/ discharges/ underground powerplants/ fixed wheel gates/ slide gates/ impact/ energy dissipation/ riprap/ research and development IDENTIFIERS-- *bellmouths/ Morrow Point Dam, Colorado/ Curecanti Unit, Colorado/ Colorado River Storage Project/ Colorado

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PURPOSE

The purpose of the model studies was to assist in developing the design of the spillway and to determine the hydraulic operating characteristics of the recommended spillway, outlet works, and power-plant tailrace.

SUMMARY OF RESULTS

1. The preliminary design of the outlet works, consisting of two high-head slide-gate-controlled conduits near the bottom of the dam, caused undesirable stilling basin flow conditions, Figures 7 through 10, and was abandoned.
2. The alternate (recommended) design consisted of four fixed-wheel gate-controlled spillway outlets located about 35 feet below the top of the dam, Figure 4, and a small slide-gate-controlled outlet works near the base of the dam, Figure 5.
3. To improve the hydraulic performance of the stilling basin at the base of the dam, the two inside spillway conduits were tipped 27° downward. The bellmouth entrances to the spillway conduits were revised to be compatible with the geometry of the conduits.
4. The shape and location of the weir were modified and the stilling basin size and shape were changed slightly to improve the energy dissipating efficiency and flow appearance of the stilling pool.
5. Extensive data concerning pressures in the bellmouth entrances and spillway conduits, on the stilling basin floor, and on the weir were obtained. Pressures in the bellmouths and conduits were slightly sub-atmospheric (8 feet of water) with the control gates 100 percent open, Figure 18. With the gates closed approximately 1 percent, all pressures were above atmospheric.

6. Pressures observed on the upstream face of the weir reflected the deviation from hydrostatic due to impact, Figure 32, and were used in the structural design of the weir. Pressures on the downstream face of the weir were steady and nearly hydrostatic.
7. The magnitude of impact pressures on the stilling basin floor varied with the discharge and the pattern of gate operation. The maximum impact head was about 200 feet of water for the maximum spillway discharge, Figure 33.
8. The discharge capacity of the spillway was measured as 40,000 cfs at maximum reservoir elevation (7165) with all four gates 100 percent open; however, most tests were restricted to a spillway discharge of 34,400 second-feet which is that required to accommodate the inflow design flood.
9. Portions of the powerplant tailrace channels and the river topography downstream from the weir were modified to improve flow conditions in those areas, particularly for the maximum discharge. The topography in the vicinity of the tailrace channels was streamlined to reduce eddies. The right river bank topography was excavated to provide some relief from a backwater effect due to a constriction in the channel. See Figures 22 through 30.
10. A floodwall on the left side of the tailraces was tested and recommended for use in the vicinity of the visitor's area to provide protection against wave action during large spillway discharges, Figure 31.
11. Minor vortex action occurred in the reservoir near the spillway entrances, particularly during large discharges, Figure 37. The observed vortices pulled small amounts of air into the conduits.
12. Undesirable surging was noted with the gates wide open and the reservoir lowered to near the top of the entrances. However, this is not an operating condition. The minimum submergence, measured from the top of the bellmouth entrances, will be about 10 feet for the inside conduits and about 17 feet for the outside conduits.
13. Extension or rounding of the corners of the vertical section on the upstream face of the dam which contains the bellmouth entrances had no effect on the bellmouth pressures.
14. Tests were made to determine the movement of rock material that may fall into the stilling basin from the cliffs on either side. It was concluded that for the maximum discharge, all material downstream from the point of impact of the jets would be swept out of the basin. For discharges less than maximum, material would be left to circulate in the basin, conceivably causing abrasive damage to the concrete lining.

Material remaining upstream from the point of impact should remain in an essentially stable position, with relatively little circulation as compared to that downstream from the impact point. Test results are shown in Figures 35 and 36.

15. Riprap protection immediately downstream from the weir was stable with the exception of movement of a small amount of material during the maximum discharge. It was also noted that some material was deposited near the downstream end of the right powerplant tailrace channel. The model indicated that the talus slope on the right side of the river channel might be subject to erosion damage.

GENERAL COMMENTS ON SPILLWAY OPERATION

Several comments on operation of the features are listed for consideration:

1. Surging in the tailrace channels may necessitate suspension of powerplant operation for spillway discharges at or near the design discharge.
2. Protection should be provided for the powerplant access tunnel to eliminate possible flooding during spillway discharges above approximately 26,000 cfs.
3. Spray from the spillway discharge may have some effect on operation of the switchyard.
4. Strong vibrations were noted in the model during large spillway discharges.
5. Inspection of the stilling basin pool lining is desirable after spillway operation, because of the possibility of abrasion damage.
6. To avoid subatmospheric pressures in the conduits, the spillway gates should be opened not more than 99 percent.
7. The spillway gates should not be opened more than approximately 75 percent unless the bellmouth entrances are submerged at least 2 or 3 feet.
8. The best flow conditions and lowest impact pressures in the stilling basin occur for symmetrical operation of the spillway with equal discharges through each of the four conduits.

ACKNOWLEDGMENT

The model studies described in this report were accomplished primarily through cooperation between the Hydraulics Branch, Division of Research and the Concrete Dams Section, Dams Branch, Division of Design. Specific phases of the study were of direct concern to personnel of the Structural and Architectural Branch and the Mechanical Branch who made frequent visits to the laboratory and offered many helpful suggestions. Also, many foreign and domestic visitors observed the model throughout the course of the study. Photography was by W. M. Batts, Office Services Branch.

INTRODUCTION

Morrow Point Dam, located on the Gunnison River, 22 miles east of Montrose, Colorado, Figure 1, is one of the key features of the Curecanti Unit of the Colorado River Storage Project. The other features include Blue Mesa Dam, upstream from Morrow Point, and Crystal Dam, downstream from Morrow Point.

Morrow Point Dam, the Bureau of Reclamation's first double-curvature, thin-arch concrete dam, contains the Bureau's first orifice-type free-fall spillway, and its first underground powerplant, Figures 2 and 3. The dam varies in thickness from 12 feet at the crest to 52 feet at the base and rises 465 feet above the foundation. It contains 360,000 cubic yards of concrete and has a crest length of 720 feet. The reservoir has a storage capacity of 117,000 acre-feet, extending upstream to within one-half mile of Blue Mesa Dam.

The spillway includes four 15- by 15-foot openings controlled by fixed-wheel gates, Figure 4, with a capacity of 40,000 cubic feet per second. The discharge jets fall freely, approximately 400 feet to a stilling basin at the base of the dam. The basin, formed by a 65-foot-high weir, is lined with 5-foot-thick concrete and is about 180 feet wide. The weir is 320 feet downstream from the dam axis.

The outlet works near the base of the dam consists of a 4- by 4-foot steel-lined conduit controlled by 3.5- by 3.5-foot tandem slide gates, Figure 5. The outlet works discharges up to 1,500 cfs. Model studies of the outlet works gates are described in a separate report.

The underground powerplant, Figures 2 and 3, located in the left canyon wall, contains two 60,000-kilowatt generators and discharges up to 5,200 cfs through two tailrace channels into the river. The river channel is improved for a distance of approximately 1,200 feet downstream from the powerplant tailrace channels.

The preliminary design of the spillway and outlet works which provided a basis for the first model tests, consisted of a free overflow spillway at the dam crest with a discharge capacity of 19,500 second-feet, and a two-conduit, slide-gate-controlled, low-level outlet works with a discharge capacity of 19,000 second-feet. The spillway discharge fell almost vertically into the stilling pool and the outlet works discharged into the pool at an angle of 15° below horizontal. The length of the stilling basin was limited by the location of the powerplant tailrace channels.

Although many modifications were tested, the outlet works arrangement was found to be unsatisfactory. The energy of the high-velocity outlet works efflux was not effectively dissipated in the stilling basin, resulting in excessive impact on the upstream face of the weir and undesirable flow turbulence and spray at the weir. The design was therefore abandoned without testing the overflow spillway. An alternative design was proposed that combined the spillway and outlet works discharges into a free-falling spillway discharge through four gate-controlled outlets near the crest of the dam. The hydraulic model studies proved this design to be satisfactory. In the preliminary design the top of the parapets on the dam and the maximum water surface were elevation 7174. The normal water surface elevation was 7160. In the recommended design the maximum water surface was elevation 7165 and the normal water surface remained at elevation 7160.

THE MODEL

The portions of the preliminary design simulated in the original 1:24 model included the slide-gate-controlled outlet works, the stilling basin, and the weir. The outlet works discharge was supplied through a pressure tank connected directly to the laboratory water supply system. Only the control gates were built; the upstream guard gates were not included in the model. The stilling basin topography was formed with concrete and the weir was formed with concrete screeded to sheet metal templates.

Following abandonment of the preliminary design, a headbox was included in which the spillway conduits and a portion of the upstream face of the dam were installed. The spillway conduits and bellmouth entrances were fabricated with sheet metal and included piezometers for pressure measurement. The fixed-wheel gates controlling the spillway flow were simulated by slide gates with correctly proportioned gate slots. The low-level outlet works was added later, with water supplied directly from the headbox. Discharge through the outlet works was controlled with a slide gate.

Piezometers were included in the stilling basin floor and the upstream face of the weir for determination of impact pressures. Final revisions included improved stilling basin topography, the powerplant tailrace channels, and a portion of the improved river channel to approximately Station 4+00.

Water was supplied to the spillway and outlet works through a recirculating system by centrifugal pumps. The combined spillway and outlet works discharges were measured by permanent volumetrically calibrated venturi meters. A portable centrifugal pump supplied the powerplant discharge which was measured by a portable orifice meter.

The tailwater was controlled with an adjustable tailgate and the tailwater elevation was measured by a staff gage at improved river channel Station 4+25. Elevations were set according to the curve of Figure 6.

Special instrumentation consisted of pressure transducers which were used to record the variation in impact pressure on the stilling basin floor and weir face and to more closely examine the pressures in the spillway conduits and bellmouth entrances. The transducers were connected to a six-channel direct writing oscillograph. The oscillograph records were analyzed with the aid of a short electronic digital computer program (see Appendix), which converted oscillograph deflections directly to prototype pressure heads.

THE INVESTIGATION

The investigation was initiated to determine the hydraulic characteristics of the preliminary design. Following abandonment of this design, the model aided in the development of the alternate scheme and provided information as to the operating characteristics of the recommended design.

The Preliminary Design

The preliminary design included an outlet works and a spillway. The outlet works consisted of two 7- by 10.5-foot conduits, located at elevation 6800 near the base of the dam and controlled by tandem high-head slide gates, which discharged at an angle of 15° below horizontal. The maximum outlet works design discharge was 19,000 cfs with the reservoir at the top of the parapet, elevation 7174. At normal reservoir elevation 7160 the outlets were designed to discharge approximately 18,600 cfs. The high-velocity jets (approximately 130 feet per second) discharged into a stilling basin formed by a 65-foot-high weir located about 180 feet downstream from the slide gates. The preliminary spillway was 132 feet wide with the crest at elevation 7162; its discharge capacity was 19,500 cfs.

The early model configuration included only the outlet works and stilling basin, Figure 7A. The spillway was to be added and tested after completion of the outlet works investigation.

Operation of the preliminary design model at the maximum discharge is shown in Figure 7B and C. The high-velocity jets were not effectively diffused in the stilling basin and struck the upstream face of the weir with great force; there was practically no energy dissipation in the basin. The initial tests indicated that the stilling basin was too short; therefore, the weir was moved downstream approximately 100 feet and the tests were repeated. Flow conditions were improved, but the flow appearance and energy dissipation were still unsatisfactory for the maximum discharge, Figure 8. Even at 50 percent gate opening, the flow conditions were undesirable. Increasing the downward tip angle of the conduits from 15° to 24° did not improve the energy dissipation or flow appearance, Figure 9.

A 24-foot-wide horizontal baffle was attached to the top of the upstream weir face, Figure 10, in an attempt to improve the energy dissipation and confine the turbulence to the stilling basin. Again, little improvement was noted in the flow conditions.

These preliminary observations indicated that a longer stilling basin was needed for adequate energy dissipation. However, the weir could

not be moved farther downstream because it would interfere with the powerplant tailrace, and the powerplant location could not be changed because of economic and geologic considerations. Other modifications of the preliminary design to achieve satisfactory operation, such as widening or deepening the basin, were considered impracticable. Therefore, the preliminary design of the outlet works and the overflow spillway was abandoned and an entirely new concept was proposed.

The Alternate Design

The alternate design consisted of four 15-foot-square conduits with their inverts at elevation 7123. All four conduits discharged horizontally. The maximum design reservoir elevation was lowered to elevation 7165. Thus, the centers of the fixed-wheel gates controlling the discharge were submerged 34.5 feet. The stilling basin design, including the weir, remained the same as at the completion of tests on the preliminary design. The four conduits, which will hereafter be referred to as the spillway, were designed to have the same capacity as the combined total discharge of the preliminary spillway and outlet works, or 38,500 cfs. In reality, the model indicated that the spillway had a discharge capacity of approximately 40,000 cfs, at the maximum reservoir elevation.

Figure 11 shows discharge from the spillway for symmetrical operation at one-fourth, one-half, three-fourths, and full maximum capacity, and the corresponding stilling basin flow conditions. The jets penetrated through the pool to the floor of the basin with a strong downstream velocity along the basin floor. This caused flow conditions at the weir similar to those observed for the preliminary design, but the flow was more evenly distributed across the width of the basin and weir.

The maximum impact pressures on the upstream face of the weir and on the stilling basin floor were measured by piezometers connected to open tube water manometers. Piezometer locations and contours of equal pressure are shown in Figure 12A; all pressures are referenced to the piezometer opening. The maximum pressure on the floor was about 120 feet of water, occurring near the bottom of the left slope of the stilling basin (Piezometer 11) about 75 feet upstream from the weir. Pressures on the upstream face of the weir varied from about 40 feet of water near the corbel to a maximum of approximately 80 feet of water near the center of the weir base (Piezometer 20). Piezometer coverage was limited to the left half of the basin and weir, assuming that the pressure distribution would be essentially symmetrical about the centerline. Later tests included more complete coverage.

Figure 13 shows operation of the spillway with approximately one-half the maximum discharge through either the two inside conduits or the two outside conduits. This operation indicated that the undesirable flow conditions at the weir were due primarily to discharge from the two inside gates. Deflecting hoods were placed on the downstream side of the inside conduits to test this premise. The hoods deflected the inside jets, causing them to strike the stilling basin water surface 75 to 100 feet upstream from the zone of impact of the outside jets. Figure 14, when compared with Figures 11 and 13, illustrates the improved stilling basin flow conditions. Figure 12B shows the reduction in impact pressure on the stilling basin floor and weir with the deflecting hoods installed. Maximum impact pressures on the stilling basin floor were reduced from 120 feet to about 70 feet of water, and the maximum impact pressure on the weir was reduced from 80 feet to about 50 feet.

Although the deflecting hoods resulted in satisfactory flow conditions, their inclusion in the recommended design was impractical because of structural design problems. Also, as the captions on Figures 11A and 14A indicate, the hoods slightly reduced the spillway discharge capacity.

A practical method to move the impact zone of the inside jets upstream and make use of a large area of the stilling basin was to tip the inside conduits downward. Computations using the path of projectile equations showed that a tip angle of 27° would cause the inside jets to strike the pool in approximately the same location as observed with the deflecting hoods. Stilling basin flow conditions were greatly improved with the tipped conduits, Figure 15, and were considered satisfactory.

Figure 16 shows the magnitude of maximum impact pressures on the weir, obtained with electronic pressure transducers and a direct writing oscillograph. The pressures indicated are instantaneous absolute maximums, and therefore cannot be directly compared with those of Figure 12, which were recorded with water manometers. A concentration of higher pressures was noted under the weir corbel for several combinations of gate operation. For example, at the maximum spillway discharge of 40,000 cfs, Figure 16A, a pressure of about 60 feet of water occurred immediately under the corbel near the center of the weir. Since this force near the top of the weir would significantly increase the over-turning moment of the weir, the corbel was removed in later studies when the model was revised to include the powerplant tailrace, outlet works, and improved downstream river channel.

Spillway Conduit Bellmouth Entrances

The original alternate design, with the four spillway conduits horizontal, included symmetrical, elliptical bellmouth entrances, designed

according to Corps of Engineers data.^{1/} With the two inside conduits tipped downward, it became necessary to modify the bellmouth entrance shapes of the two inside conduits. The inside bellmouths were modified to include an approximate ogee crest shape on the conduit bottom, with the roof a combination of an elliptical curve and a reverse curve approximately paralleling the downstream end of the ogee section. The sides remained elliptical as before. Figure 4 shows the recommended configurations. The model was changed to include one revised bellmouth and the upstream face of the dam was simulated for the two right conduits, Figure 17. Sixty-eight piezometers were installed in the two right conduits to determine the effects of the bellmouth shapes on the pressure distribution. Piezometer locations and pressure profiles for 100 percent gate opening are shown in Figure 18. The pressures were obtained from water manometers, and in all cases the pressures exhibited negligible fluctuation.

Under maximum reservoir head, Figure 18A, subatmospheric pressures as low as approximately 6 feet of water occurred on the roof of the horizontal conduit. Pressures on the roof were above atmospheric from the entrance to a point about 7 feet downstream from the entrance and throughout the conduit floor. Subatmospheric pressures as low as 8 feet of water existed on the floor of the tipped conduit, between the gate and a point about 7 feet downstream from the entrance. Subatmospheric pressures as low as 5 feet of water occurred on the conduit roof between the gate and a point about 3 feet downstream from the entrance.

A pressure of 9 feet of water below atmospheric was recorded at Piezometer 66 in the horizontal conduit during one test run. Attempts to repeat this reading showed a subatmospheric pressure of only 3 feet of water. The former reading was apparently caused by separation of the flow from the conduit roof. It is expected that either condition could exist in the prototype. Slight subatmospheric pressures were observed on the floor of the horizontal conduit downstream from the gate (Piezometers 59-61); these low pressures apparently were caused by the slight divergence of the floor and the tendency of the jet to separate from the invert.

Pressures were also recorded with the reservoir at normal elevation to determine the effect of reduced upstream head on the pressure magnitude. This would not be a prototype condition, since full gate opening is required only at the maximum reservoir elevation. Figure 18B shows a pressure distribution similar to that of Figure 18A, except that the subatmospheric pressures are not as low because of lower velocities through the conduits. The slight subatmospheric pressures on the conduit floor downstream from the gate in the horizontal conduit (Piezometers 59-61) and the apparent flow separation on the roof of the horizontal conduit (Piezometer 66) were again noted.

^{1/}"Investigation of Entrance Flared in Four Directions," Entrances to Conduits of Rectangular Cross Section, Report No. 1, Technical Memorandum No. 2-428, Waterways Experiment Station, March 1956.

The tests showed that if the gates were closed slightly (approximately 1 percent), so that the bottom of the leaf controlled the flow, pressures at all points upstream from the gates were above atmospheric.

Revision of the Model to Include Additional Details

Since model data indicated that the revised design would provide satisfactory operation, it was decided to include additional details to more accurately evaluate the hydraulic performance of the structure.

The recommended bellmouth spillway entrances were installed in the head box, and the upstream face of the dam was correctly simulated. The stilling basin topography was reshaped to correspond to the most recent field surveys. The weir was modified to eliminate the corbel, making the upstream face vertical, and was placed so that the vertical face was 320 feet downstream from the dam axis. The 3.5-foot-square outlet works was installed near the base of the dam to discharge into the stilling basin. The outlet works flow was supplied from the head box and controlled by a slide gate.

The powerplant tailrace channels and a portion of the improved downstream river channel were also included. The powerplant discharge was supplied by a portable centrifugal pump and was measured by a portable orifice meter.

Development of Details of the Recommended Design

Stilling basin topography. --The right spillway jet struck the topography near the intersection of the right bank and the pool water surface, while the left spillway jet cleared the topography by some distance. This indicated that the model basin layout might be in error. A careful check of the model topography revealed that the right bank was 2 to 3 inches too near the centerline. The left topography was correctly simulated except near the dam and the weir. These errors were considered too small to materially affect the flow conditions in the basin. Therefore, the right side of the basin was widened about 3 feet (prototype) (making the right side 7 to 9 feet wider than originally represented in the model) so that the right jet would not strike the topography. The top of the lining was raised 10 feet (prototype) between the weir and a point 140 feet downstream from the dam axis. From this point, the top of the lining sloped downward at 6:1 toward the dam until intersecting the original top of lining. The left side of the basin near the weir was made 3 to 6 feet narrower than before. Figure 19 shows the flow conditions in the revised stilling basin for spillway discharges of 40,000 and 20,000 cfs.

Test discharges. --Up to this time, the model operation had been based on the total capacity of the spillway with all gates wide open under maximum reservoir head, which resulted in a discharge of approximately

40,000 cfs. With an outlet works discharge of 1,500 cfs and a powerplant discharge of 5,200 cfs, the total river flow was approximately 46,700 cfs.

Since the actual inflow design flood peaks at about 41,100 or 5,600 cfs less than the above indicated capacity, it could be released as a spillway discharge of 34,400 cfs, plus 1,500 cfs through the outlet works and 5,200 cfs through the powerplant. Subsequent tests included runs at the maximum spillway capacity of 40,000 cfs, the design discharge of 34,400 cfs, and three-fourths, one-half, and one-fourth of the design discharge, with the outlet works and powerplant operating as described above. Another possible operating condition consisted of the total design inflow discharging through the spillway and outlet works, with the powerplant shut down. This condition corresponds to a spillway discharge of 39,600 cfs (41,100 minus 1,500 through the outlet works). This is nearly the same as the maximum spillway capacity and was therefore not included in the model test program.

Impact pressures on the stilling basin floor and weir.--Earlier tests indicated that the corbel on the upstream face of the weir was causing a concentration of high pressures immediately under the corbel, Figure 16. The revised weir configuration, with the corbel removed, showed substantially lower pressures near the top of the weir, Figure 20. In general, the pressure increased with an increase in depth, without the isolated high pressures which were noted previously.

The impact zones of the outside jets on the stilling basin floor were clearly apparent, Figure 21. For the maximum spillway capacity of 40,000 cfs, Figure 21A, the maximum impact pressure for the outside jets was about 200 feet of water and the maximum impact pressure for the inside jets was about 340 feet of water (referenced to the piezometer opening). For the maximum design discharge of 34,400 cfs, Figure 21B, these pressures in both areas were approximately 200 feet. The model piezometer distribution did not allow determination of the configuration of the impact zones of the inside jets; however, the patterns should be similar to those observed for the outside jets. Pressures under the right outside jet were higher than those under the left outside jet because the topography was closer to the water surface on the right side.

Impact pressure patterns for other conditions of symmetrical and asymmetrical gate operations are also shown in Figure 21. Figure 21E demonstrates the effect of the shallow pool in the right side of the stilling basin; no concentrated impact is apparent from the left outside jet. Figure 21F again indicates that the piezometer coverage was inadequate to define the impact zone of the inside jets. The maximum impact of 239 feet of water compares closely with the impact of 250 feet observed

with the outside gates operating alone, Figure 21G. These impact pressures fluctuated at a frequency of about 3 to 5 cycles per second over a maximum range of approximately 100 feet of water.

Flow conditions in the powerplant tailrace. --The extreme turbulence which occurred in the stilling basin for spillway discharges greater than approximately 26,000 cfs resulted in large waves and surges which were carried downstream to the powerplant tailrace, as shown in Figure 19B. The topography surrounding the tailrace channels was subjected to sudden large impact forces because of these flow conditions. Also, there was a drawdown in the water surface at the downstream end of the left bank of the left tailrace channel during operation of the powerplant alone, Figure 22A. The tailrace topography was modified to alleviate the possibility of the rock being dislodged by these flow conditions and falling into the tailraces. The area between the tailraces was shortened and rounded to eliminate thin sections, Figure 22B. The right bank of the right tailrace channel was shortened and rounded and the left bank of the left tailrace channel was rounded, Figure 22B.

The relatively narrow entrance to the improved channel downstream from the weir acted as a control section, causing high tailwater immediately downstream from the weir and a drop in the water surface at the control section, Figure 23. The right channel bank, which is a talus slope in the prototype, was excavated in an attempt to alleviate the backwater condition. Figures 24 through 27 show flow conditions immediately downstream from the weir and in the stilling basin. The excavation resulted in the control section being moved farther downstream, causing some improvement, even though the backwater condition was not eliminated. The visitor's area on the left bank and the gate deck at the upstream end of the tailrace were periodically inundated during the maximum design discharge.

To improve flow conditions at the weir, the piers on either side of the weir were removed and the stilling basin lining was extended downstream. In addition, the topography at the right downstream end of the right tailrace channel was revised by cutting off the thin tapering rock section. The modified basin and tailrace are shown in Figure 28. Although there was no apparent improvement in the flow conditions in the tailrace area, Figure 29B, the stilling basin flow conditions were slightly improved, Figure 30.

The topography between the tailrace channels was modified in an attempt to reduce wave action in the left tailrace channel near the visitors' center parking area. The elevation of the top of the topography was increased first by 5 feet and then by 10 feet. The 5-foot increase was ineffective, but the 10-foot increase reduced the splashing during the

maximum design discharge. A 4-foot-high floodwall around the visitors' center was also tested, Figure 31. The floodwall protected the area from inundation for spillway discharges below approximately 26,000 cfs. At 26,000 cfs, minor infrequent splashing over the wall occurred. At a spillway discharge of about 31,000 cfs, large waves frequently overtopped the wall. For discharges above 31,000 cfs, the wall was ineffective.

Because of the infrequency of occurrence of the design discharge, it was decided not to attempt additional improvements to the stilling basin and tailrace channel flow conditions. Also, since the spillway and outlet works were capable of discharging the maximum design inflow, power-plant operation could be suspended during high spillway flows.

Impact pressures (recommended design). -- Impact pressures were obtained on the stilling basin floor and weir of the recommended design, Figures 32 and 33. Pressure patterns on the floor and weir were similar to those shown in Figures 20 and 21 and the previous discussion applies. However, the magnitudes of the maximum impacts were in general less in the more recent data. The figure captions show that some of the test discharges were lower in the final tests. Asymmetrical flow conditions in the initial tests included wide open gates, ($Q = 20,000$ cfs) while for the recommended design the gate openings were limited to allow a discharge of only one-half the design discharge (17,200 cfs). Therefore, the lower impact pressures observed in the final tests were probably due to the lower discharges.

Pressure fluctuations on the downstream face of the weir were relatively steady, with the largest fluctuation being approximately plus or minus 2 feet of water for the maximum design discharge. The average magnitude of the pressures was approximately hydrostatic, i.e., due to the tailwater depth alone.

The frequency distributions of the pressures at several representative piezometers on the basin floor were determined. For example, at Piezometer 24 on the stilling basin floor, for one-half spillway design discharge of 17,200 cfs, Figure 33G, the absolute maximum pressure was approximately 110 feet of water; however, a pressure with one-half the maximum magnitude (55 feet of water) occurred about 70 percent of the time, Figure 34.

Riprap test. -- The stability of the protective riprap on the channel floor immediately downstream from the weir was estimated by operating all gates symmetrically for a representative time interval at one-fourth, one-half, three-fourths, and full design discharge. After 2 hours (equivalent to about 10 hours prototype operation) at one-fourth the design discharge, very slight movement of the riprap

was noted. No further movement was observed after 1 hour operation at either one-half or three-fourths design discharge. After 1 hour operation at the design discharge (34,400 cfs), several pieces were removed from the upstream left corner of the riprap layer and material along the right side of the layer was washed toward the center of the layer. No material was observed to move into the tailrace. The rock used in the model had a maximum size of 2 to 3 inches, which is representative of the specified prototype material, with a maximum dimension of 5 feet.

Movement of rock in the stilling basin. --The possibility exists that rock from the cliffs above the stilling basin could fall into the basin and cause abrasive damage during operation of the spillway. A series of tests was made to determine movement of material in the basin for several spillway discharges. Material of the same size used in the riprap test was placed in the bottom of the stilling basin and sections were identified with white spray paint, Figure 35A. The model was operated for 1 hour for each of the discharges used for the riprap test, and for operation of the outlet works alone with no spillway discharge.

Independent operation of the outlet works caused no movement of the rock material. After symmetrical operation of all gates at one-fourth design spillway discharge, the material remained relatively stable except in the impact zone of the jets. The material was piled immediately downstream from the impact zone, Figure 35B. Figure 35C shows that with one-half design discharge, material was swept against the weir. Some material was swept over the weir and deposited immediately downstream. Three-fourths design discharge showed similar results with more material swept out of the basin, Figure 35D. The design discharge resulted in essentially complete removal of all material downstream from the impact zone, Figure 36A. Figure 36B shows a closeup of the tailrace and the amount of material deposited downstream from the weir. A small amount of material was deposited in the right tailrace channel. The tests indicated that material which falls into the basin will circulate during operation of the spillway with probable accompanying abrasive damage to the concrete lining.

Reservoir flow conditions. --Observations were made of flow conditions in the reservoir near the spillway entrances to determine possible adverse operating conditions. With the reservoir water surface at the maximum elevation (7165) and with all four spillway gates 100 percent open, discharge = 40,000 cfs, small vortices formed at the corners of the vertical section on the upstream face of the dam which contains the bellmouth entrances, Figure 37A. At times, these vortices became large enough to take small quantities of air. Smaller vortices formed over the inside bellmouth entrances, taking minute quantities of air.

Strong circulation was apparent above the outside entrances, but no vortices formed. For 39,600 cfs, with the gates slightly closed, conditions were similar to those described above.

At a spillway discharge of approximately 27,500 cfs, with the gates 100 percent open, the reservoir water surface was immediately below the top of the two inside entrances. The inside conduits flowed full for a short period of time, increasing the discharge, and the reservoir dropped so that a free water surface existed through the conduits. The lower reservoir elevation resulted in a decreased discharge and the reservoir elevation increased until the conduits again flowed full. This cycle was repeated and resulted in a periodic surging with a frequency of about one surge per second. Such a condition could cause undesirable flow conditions in the conduits and vibration in the gate mechanisms. With one inside gate closed about 25 percent, surging was eliminated in that conduit but continued in the other inside conduit. By closing one of the outside gates to increase the reservoir elevation, surging was stopped in both inside conduits when the water surface rose 2 to 3 feet (prototype) above the top of the entrances. Similar surging was noted in the outside conduits with the water surface near the top of the outside entrances, and was eliminated by a gate closure of about 25 percent. The surging condition is a function of the conduit geometry and a critical reservoir elevation and can be eliminated by gate closure or adequate submergence of the entrances. According to the prototype operating criteria, the conditions described above will not be allowed to occur. The minimum submergence, measured from the top of the bellmouth entrances, will be about 10 feet for the inside conduits and about 17 feet for the outside conduits.

With either the two inside or two outside conduits operating alone with the gates 100 percent open and the reservoir at elevation 7160, vortex action similar to that described for the maximum spillway discharge was observed. At three-fourths maximum discharge, with the gates equally open and the reservoir at elevation 7160, Figure 37B, the vortex was somewhat stronger and larger than that observed for the maximum discharge because of the lower reservoir elevation. Vortex action diminished with a further decrease in discharge, until at one-half maximum discharge only a dimpled water surface was observed above the entrances.

Modifications to the corners of the vertical face were tested in the model to determine if such modifications would improve the pressure distribution in the outside bellmouth entrances. First, the right corner of the vertical face was extended 12 feet (prototype) away from the entrance. No noticeable change occurred in the bellmouth pressures. The extension was removed and a 4-foot radius rounding was applied to the right corner. Again, no change was noted in the pressure distribution. On the basis of these observations, no modifications were made to the prototype design.

Spillway discharge capacity. -- The discharge capacity of the recommended spillway was determined for various conditions of symmetrical and asymmetrical operation. With all four gates 100 percent open, the discharge capacity was 40,000 cfs at reservoir elevation 7165. The capacity of the two outside conduits, with the inside gates closed, was 20,000 at reservoir elevation 7165. The corresponding capacity of the two inside conduits was also 20,000. One inside conduit operating alone discharged 10,000 cfs at elevation 7165, as did one inside gate alone. Data for operation at partial gate openings, which would occur in the range between normal and maximum reservoir elevations, were not obtained.

The model gates did not correctly simulate the prototype gates, and it was felt that such data would not be sufficiently accurate.

Miscellaneous observations. -- The average elevation of the backwater on the downstream face of the dam was found to be 6780 for the design spillway discharge, with waves as high as elevation 6790. For one-half design discharge, the backwater stood at an average elevation of 6770. The downstream tailwater was set for the total river flow, including the outlet works and powerplant discharges.

Operation of the low-level outlet works was satisfactory either with or without the spillway operating.

The feasibility of calibrating the model weir was investigated, to determine the possibility of using the prototype weir for discharge measurement. With only the outlet works operating, the stilling basin water surface was too rough to allow an accurate elevation reading. Also, the two 3-foot-square openings in the weir would not be easily plugged. Use of the prototype weir for this purpose was therefore considered impractical.

Photographs of operations of the recommended design are shown in Figures 38 through 44. Colored movies (including slow motion) were also taken for future reference.

Table 1

Metric Equivalents of Important Quantities

Feature	English units	Metric units
Dam thickness at crest	12 feet	3.66 meters
Dam thickness at base	52 feet	15.85 meters
Dam height above foundation	465 feet	141.73 meters
Volume of concrete	360,000 cubic yards	273,600 cubic meters
Length at crest	720 feet	219.46 meters
Reservoir capacity	117,000 acre-feet	144,319,500 cubic meters
Reservoir length	12 miles	19.31 kilometers
Spillway capacity	40,000 cfs	1,132 m ³ /sec
Spillway gate size	15 feet square	4.57 meters square
Height of fall	400 feet	121.92 meters
Stilling pool length	320 feet	97.54 meters
Stilling pool width	180 feet	54.86 meters
Weir height	65 feet	19.81 meters
Lining thickness	5 feet	1.52 meters
Outlet works capacity	1,500 cfs	42.45 m ³ /sec
Outlet works gate size	3.5 feet square	1.07 meters square
Powerplant generation	120,000 kilowatts	120,000 kilowatts
Powerplant discharge	5,200 cfs	147.16 m ³ /sec

APPENDIX

APPENDIX

Electronic Digital Computer Program for Calculation of Maximum Instantaneous Impact Pressures

The subject computer program was written for the purpose of calculating prototype pressures from deflections on an oscillograph recording obtained with electronic pressure transducers. The program is short, but practical because of the large volume of data analyzed.

The program is written in the FORTRAN II (FORmula TRANslation) language. No special operating procedures are required. The program can be used on most digital computers. Input data consist of the test run number and piezometer number for identification; the maximum, minimum, and average stylus deflection (in millimeters) from the oscillograph record, and calibration and sensitivity data for the recording instrument. A zero datum plane correction factor and the model scale are also included as input. A sample data sheet is included in this appendix.

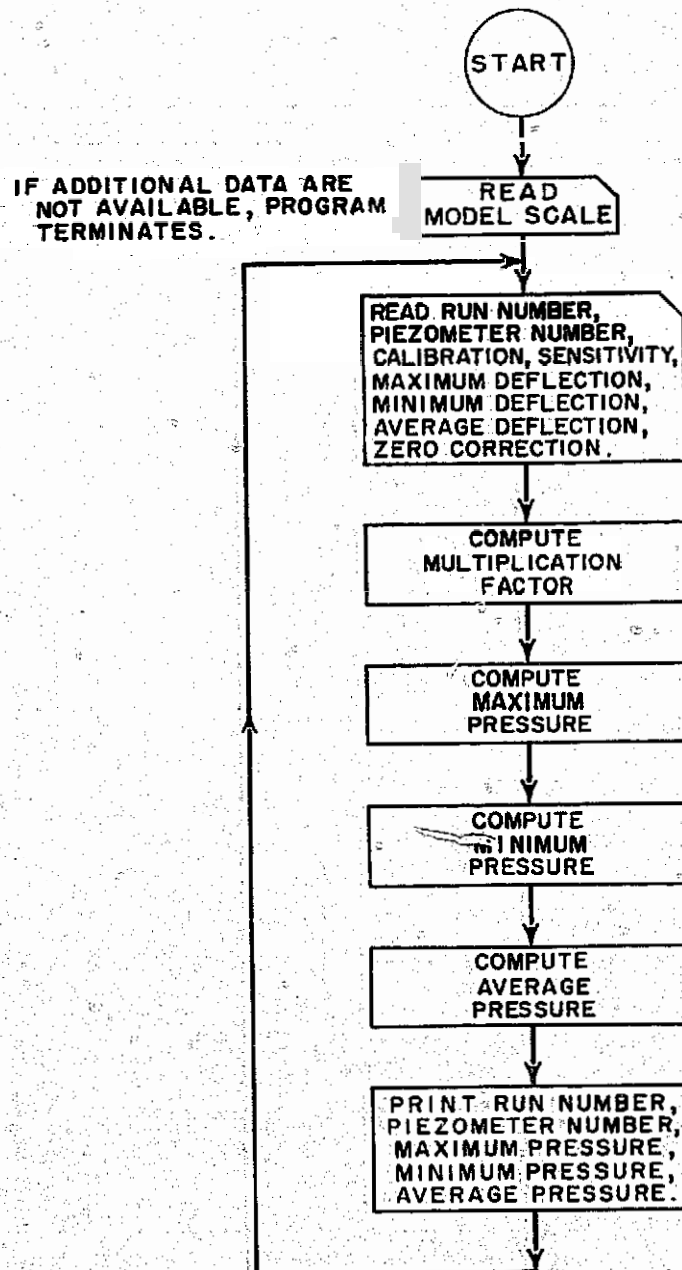
A multiplication factor is computed from the sensitivity, calibration, and model scale. This factor is applied to the stylus deflections, resulting in the prototype pressure heads, in feet of water, which are adjusted to the piezometer opening for zero datum with the zero correction factor. These steps are presented in the flow chart and program listing. Output consists of the identifying run and piezometer numbers, and the maximum, minimum, and average prototype pressure heads as shown on the output listing in this Appendix.

Approximately 800 oscillograph records were analyzed, corresponding to about 7,000 computation steps.

DEFINITION OF VARIABLES USED IN THE PROGRAM

SCALE	Model scale
RUN	Test run number
PIEZ	Piezometer number
CALIB	Recorder attenuation at which 1.0 foot of water results in a stylus deflection of 10 mm
SENS	Recorder attenuation setting for test run
DEFMAX	Maximum stylus deflection for test run
DEFMIN	Minimum stylus deflection
DEFAVE	Average stylus deflection
ZEROC	Correction factor to shift zero datum to piezometer opening
FACTOR	Multiplication factor to change stylus deflection to prototype pressure head
PRMAX	Maximum prototype pressure head
PRMIN	Minimum prototype pressure head
PRAVE	Average prototype pressure head

Variables are defined in the order in which they first appear in the program.



FLOW CHART FOR DIGITAL COMPUTER
CALCULATION OF INSTANTANEOUS
IMPACT PRESSURES

PROGRAM LISTING

CALCULATION OF INSTANTANEOUS PRESSURES

MORROW POINT DAM SPILLWAY MODEL
1 FORMAT (F8.0)
2 FORMAT (2I8,6F8.0)
3 FORMAT (I8,1X,I8,6X,F8.1,9X,F8.1,11X,F8.1)
40FORMAT (1H1,73H RUN NO PIEZ NO MAXIMUM PRESS MINIMUM P
1RESS AVERAGE PRESS)
50FORMAT (1H0,75H PRESSURES ARE IN PROTOTYPE FEET OF WATER MEASURED
1ABOVE PIEZOMETER OPENING)
WRITE OUTPUT TAPE 6,5
WRITE OUTPUT TAPE 6,4
READ INPUT TAPE 5,1,SCALE
6 READ INPUT TAPE 5,2,RUN,PIEZ,CALIB,SENS,DEFMAX,DEFMIN,DEFAVE,ZEROC
FACTOR=(SENS*SCALE)/(CALIB*10.0)
PRMAX=DEFMAX*FACTOR+ZEROC
PRMIN=DEFMIN*FACTOR+ZEROC
PRAVE=DEFAVE*FACTOR+ZEROC
WRITE OUTPUT TAPE 6,3,RUN,PIEZ,PRMAX,PRMIN,PRAVE
GO TO 6
END(1,0,0,0,0,0,1,0,0,0,0,0,0,0,0,0)

EXAMPLE OF OUTPUT LISTING

RUN NO	PIEZ NO	MAXIMUM PRESS	MINIMUM PRESS	AVERAGE PRESS
19	36	47.9	22.5	33.0
19	29	51.4	-2.0	33.0
19	37	63.5	26.9	34.7
20	35	37.8	16.4	28.6
20	36	36.9	16.8	28.6
20	29	38.2	13.7	28.6
20	37	38.6	24.2	30.2
21	35	36.5	-5.5	19.0
21	36	37.4	11.1	19.0
21	29	55.7	-19.5	24.2
21	37	45.2	19.0	28.6
22	35	46.1	10.2	27.7
22	36	43.9	14.2	27.7
22	29	57.5	-2.0	33.0
22	37	37.9	22.8	29.5
23	35	40.9	2.4	28.6
23	36	45.2	19.0	29.5
23	29	39.1	6.7	24.2
23	37	45.9	22.1	30.9
24	35	45.7	10.7	27.7
24	36	36.9	19.0	27.7
24	29	63.6	12.0	33.0
24	37	38.6	22.1	29.5
25	35	30.8	14.6	22.5
25	36	29.9	11.1	21.6

FIGURE 1
REPORT HYD-557

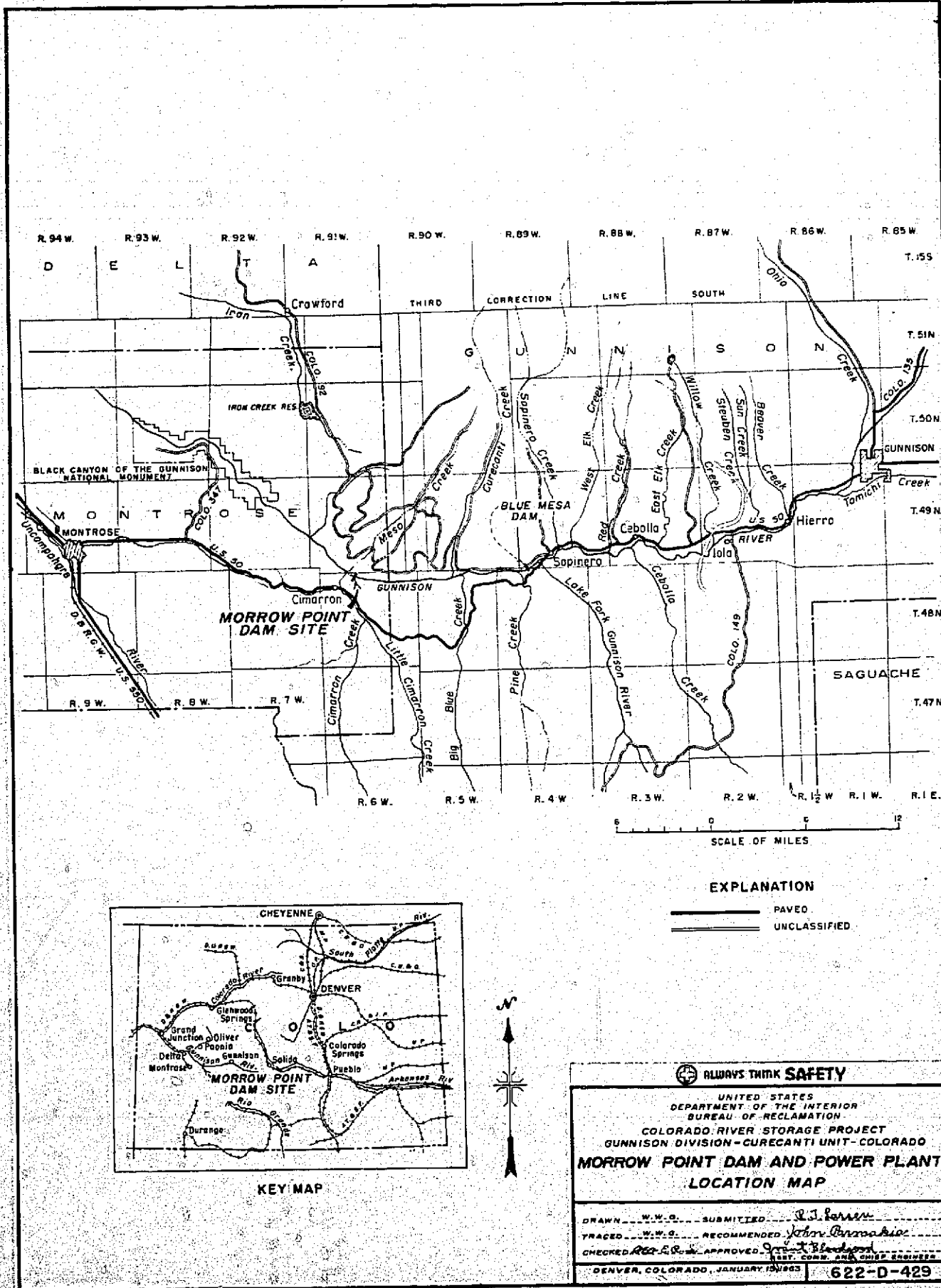
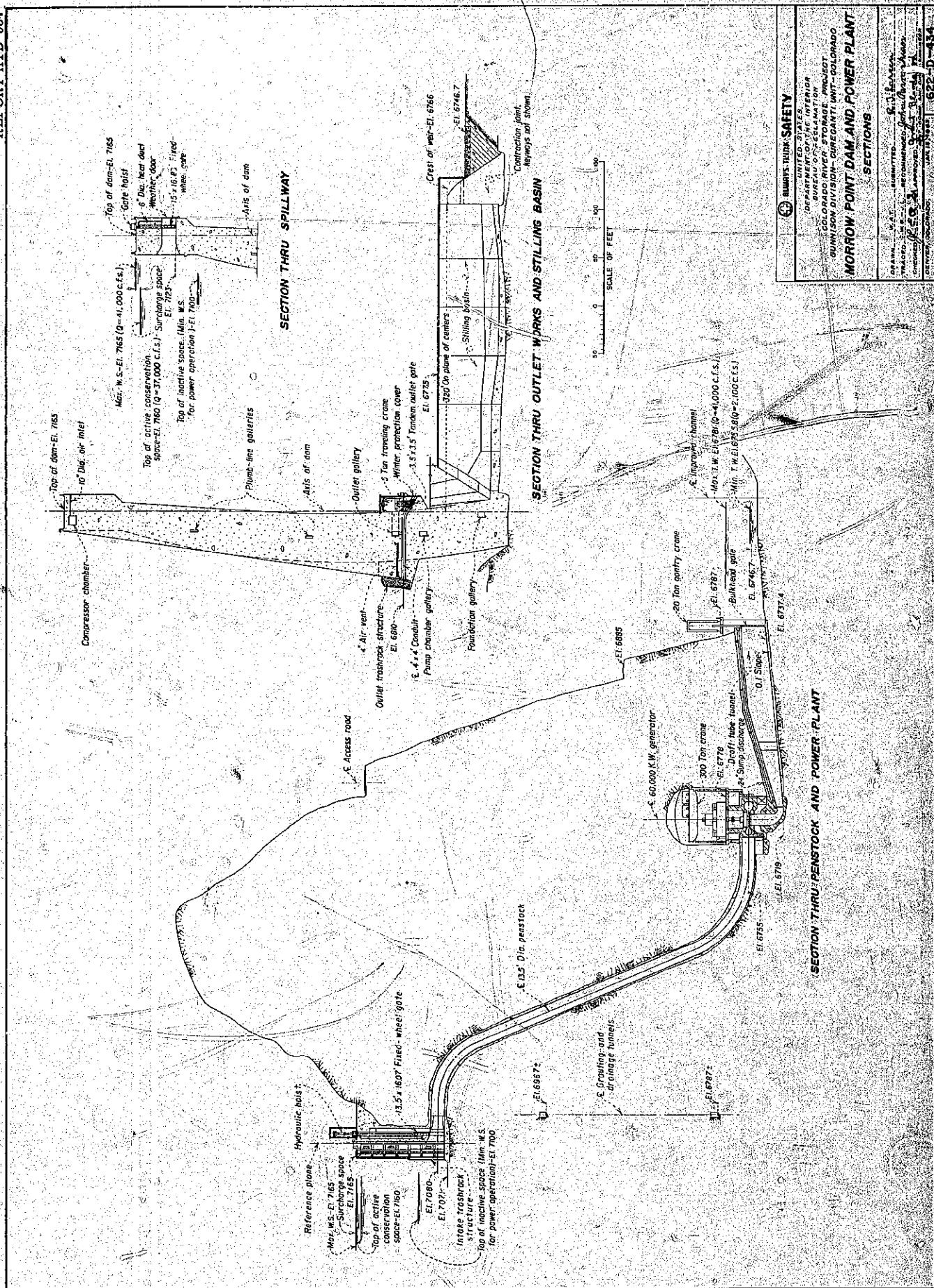


FIGURE 3
REPORT HYD-557



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO
DIVISION OF CONSTRUCTION
GUNNISON DIVISION - GUNNISON UNIT - COLORADO

MORROW POINT DAM AND POWER PLANT
SECTIONS

DESIGNED BY: *[Signature]*
CHECKED BY: *[Signature]*
APPROVED BY: *[Signature]*
SUBMITTED: 8-11-55
TRACED: 8-11-55
RECORDED: 8-11-55
INDEXED: 8-11-55
DRAWN: 8-11-55
DATE: 8-11-55
PROJECT: 622-D-434

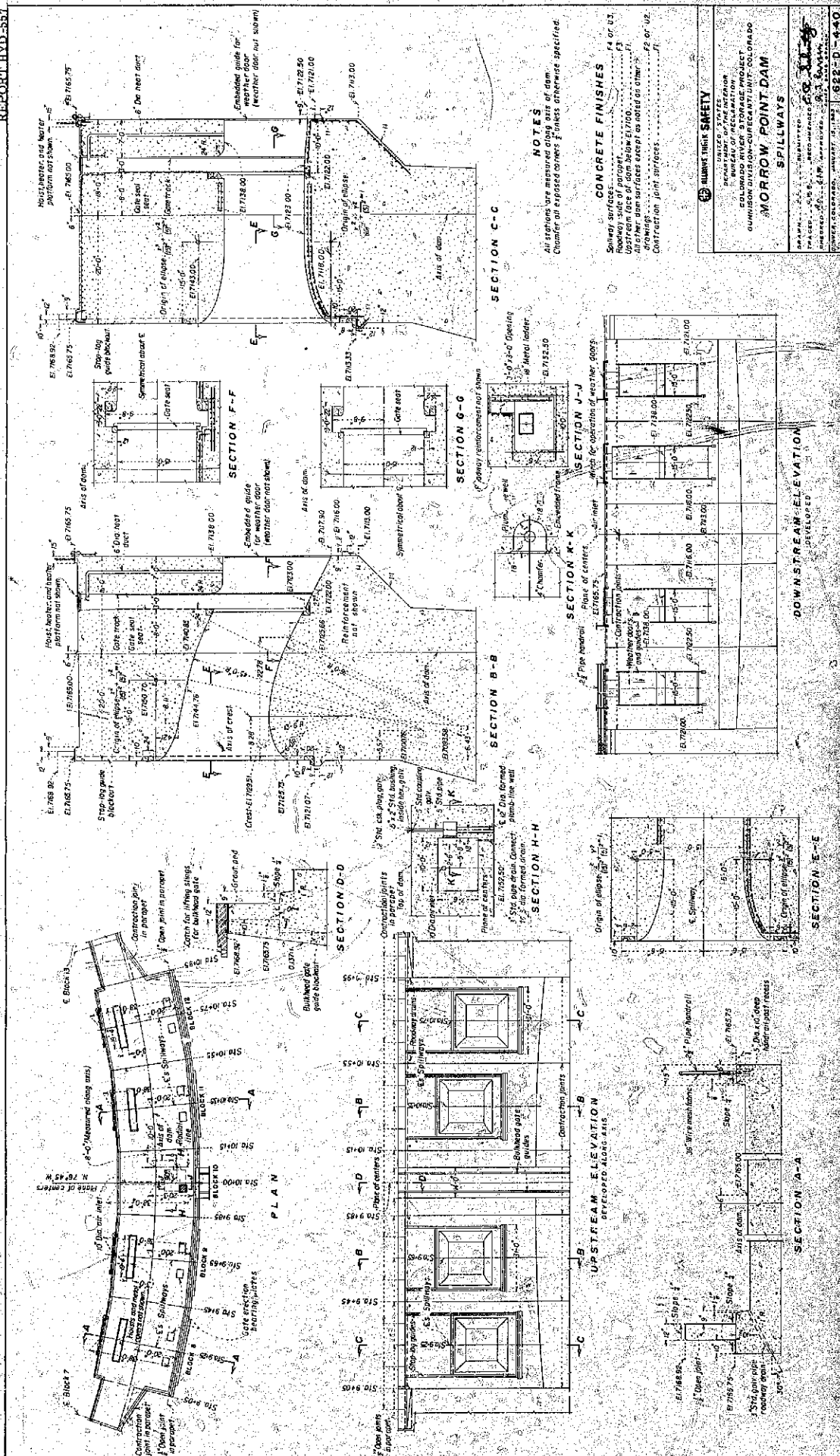
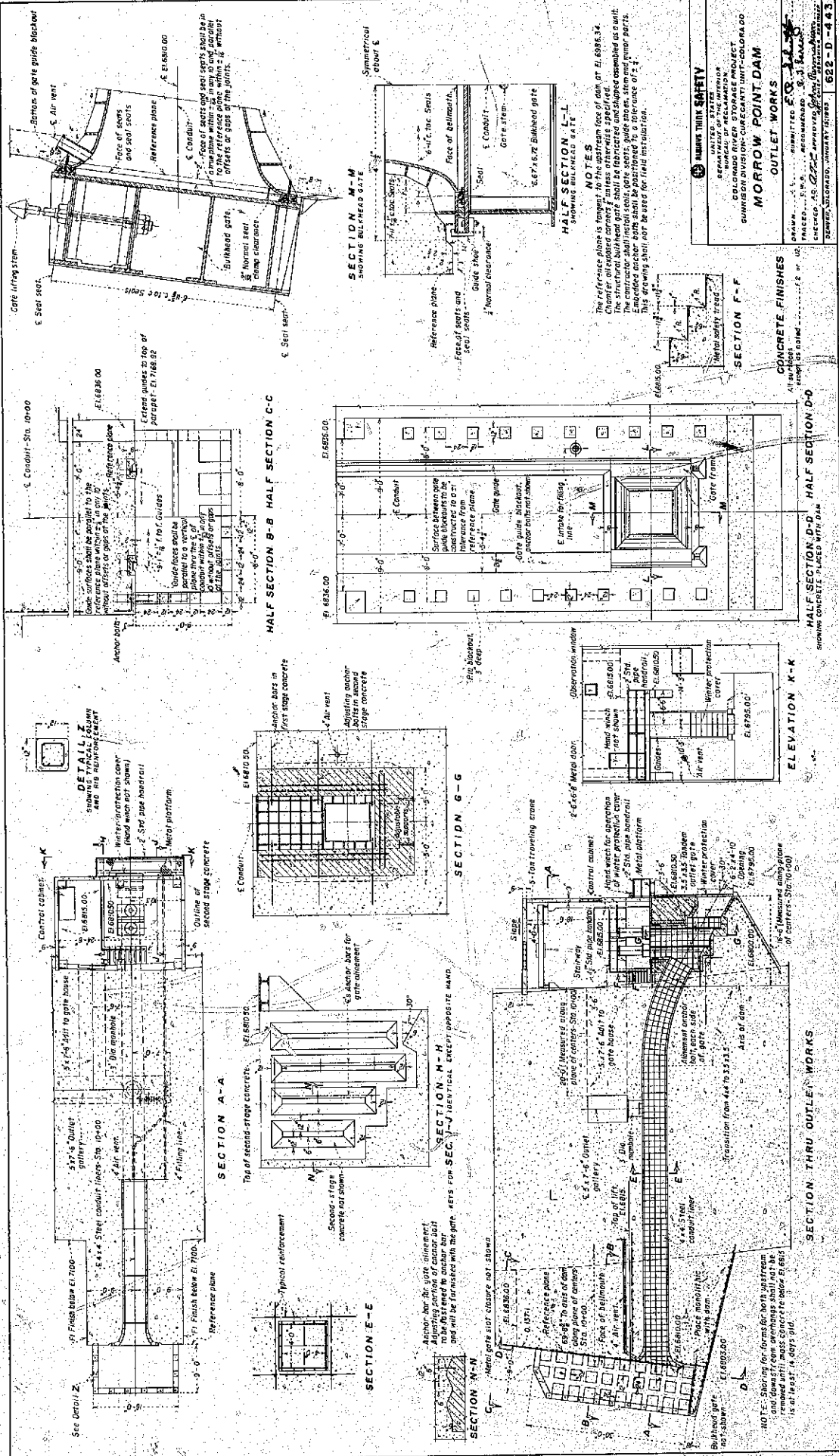
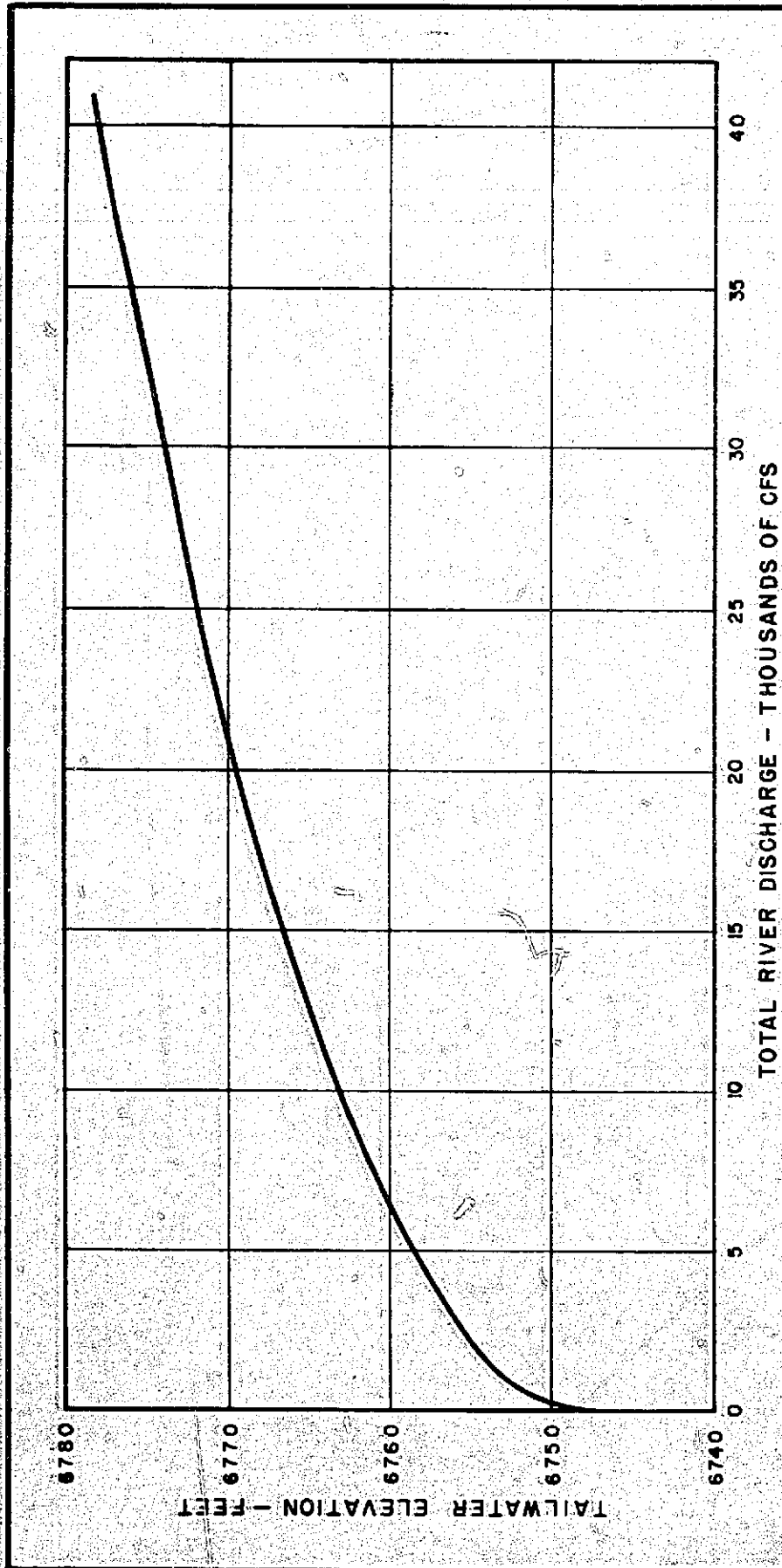
FIGURE 4
REPORT HYD-

FIGURE 5
REPORT HYD-557

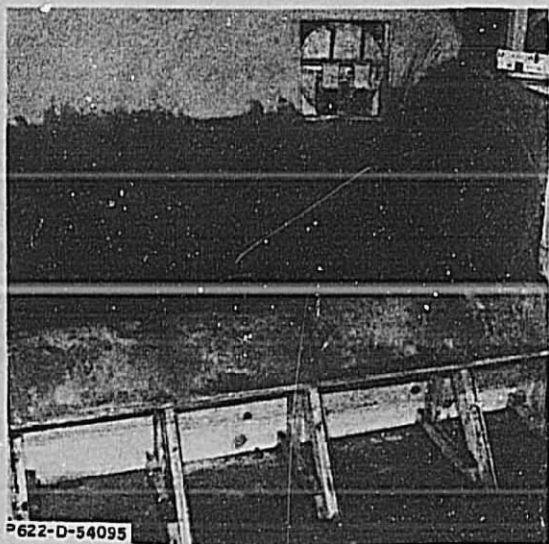




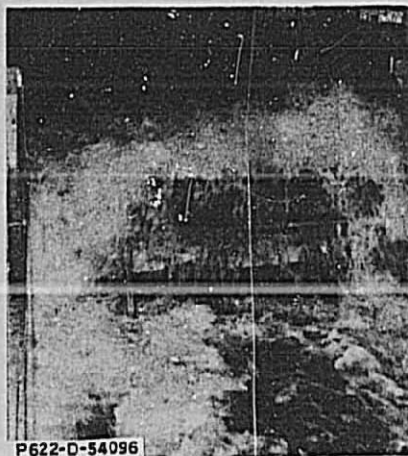
Note: Measuring station 425 feet downstream from axis of weir. Curve derived from Figure 5B, "Tailwater Study for Final Design Purposes" Hydrology Branch, December 1962.

MORROW POINT DAM
TAILWATER CURVE

FIGURE 7
REPORT HYD-557



A. Preliminary design



B. 100% gate openings
 $Q = 19,000$ cfs

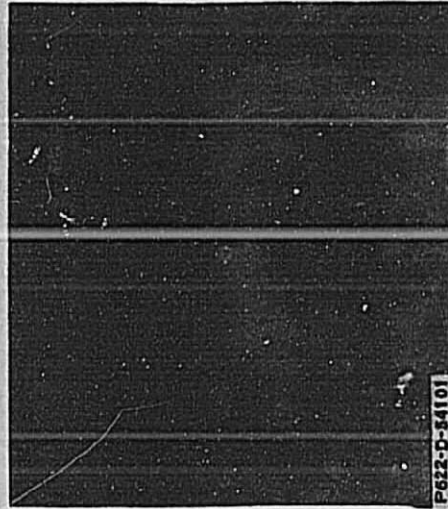
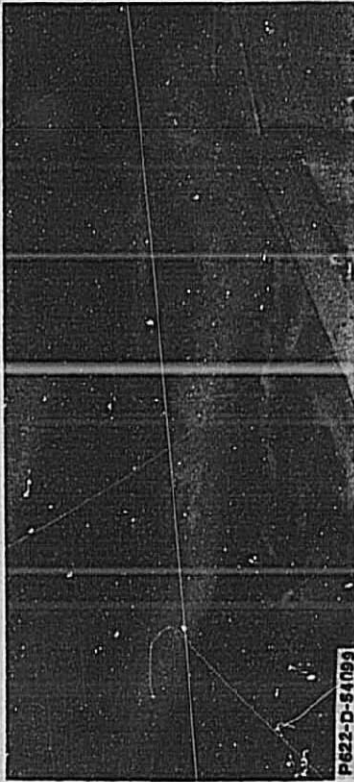


C. 100% gate openings
 $Q = 19,000$ cfs

MORROW POINT DAM OUTLET WORKS
PRELIMINARY DESIGN
1:24 Scale Model

Stilling Basin Flow Conditions
Gates Tipped 15° Below Horizontal

FIGURE 8
REPORT HYD-557



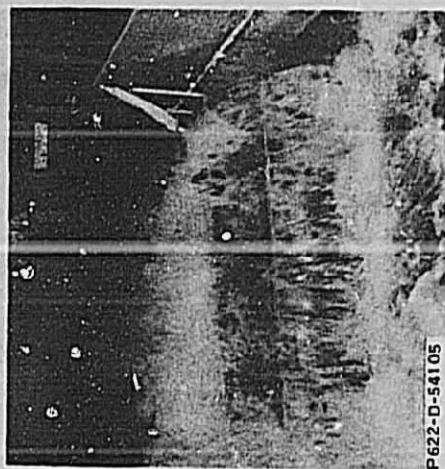
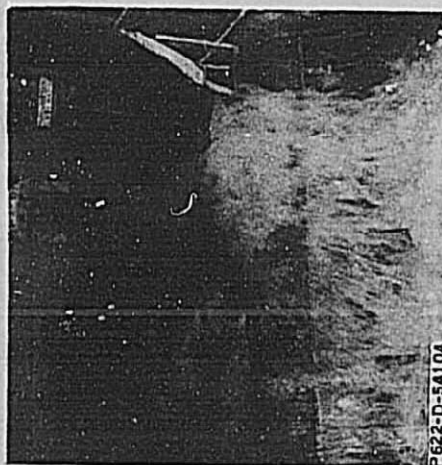
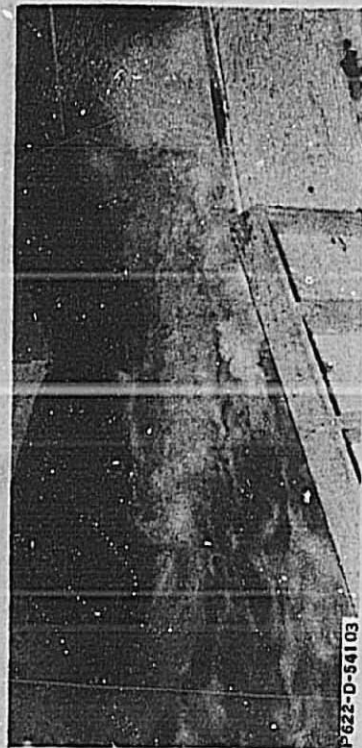
A. 50% gate openings
 $Q = 8,180$ cfs

B. 100% gate openings
 $Q = 19,000$ cfs

MORROW POINT DAM OUTLET WORKS
PRELIMINARY DESIGN
1:24 Scale Model

Stillling Basin Flow Conditions
Gates Tipped 15° Below Horizontal
Weir 100 feet Downstream from Original Position

FIGURE 9
REPORT HYD-557



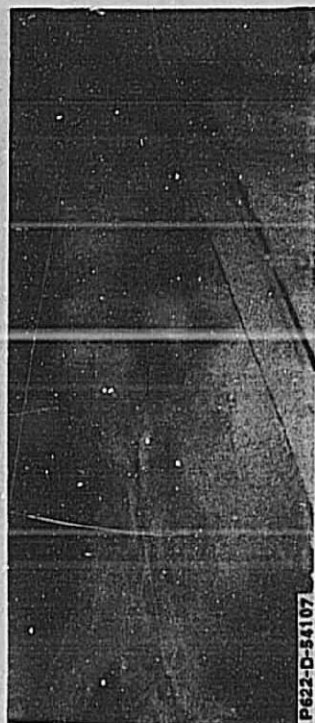
A. 50% gate openings
 $Q = 8,180$ cfs

B. 100% gate openings
 $Q = 19,000$ cfs

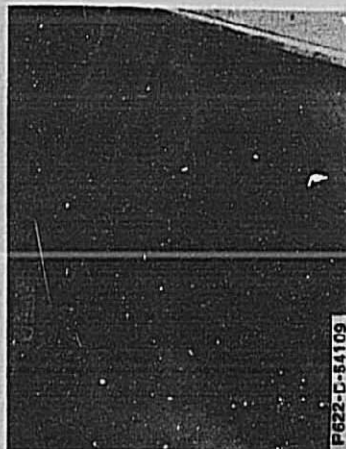
MORROW POINT DAM OUTLET WORKS
PRELIMINARY DESIGN
1:24 Scale Model

Stilling Basin Flow Conditions
Gates Tipped 24° Below Horizontal

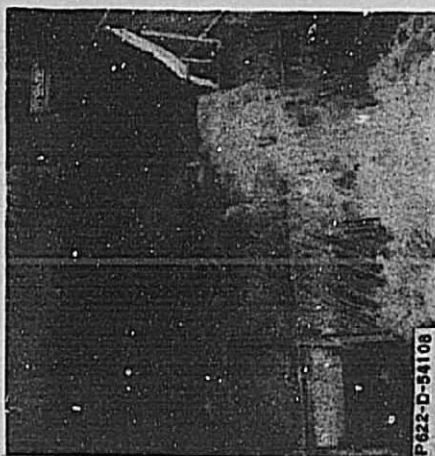
FIGURE 10
REPORT HYD-557



C. 100% gate openings
 $Q = 19,000$ cfs



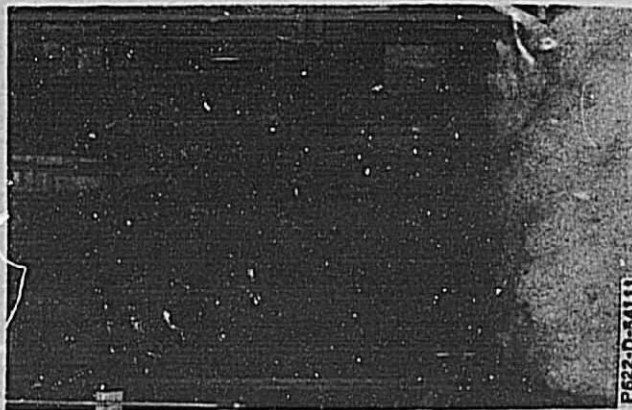
A. Upstream face of weir with
24-foot-wide horizontal baffle.



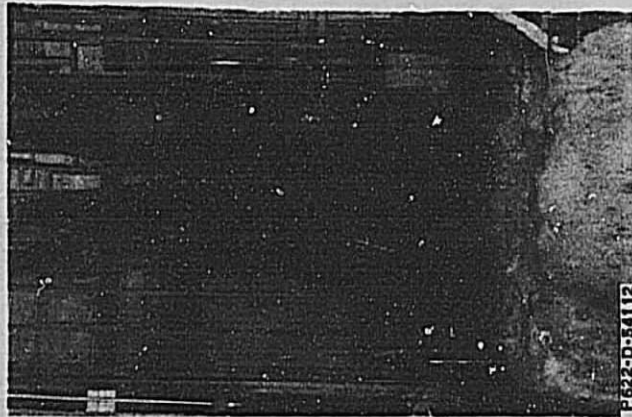
B. 50% gate openings
 $Q = 8,180$ cfs

MORROW POINT DAM OUTLET WORKS
PRELIMINARY DESIGN
1:24 Scale Model

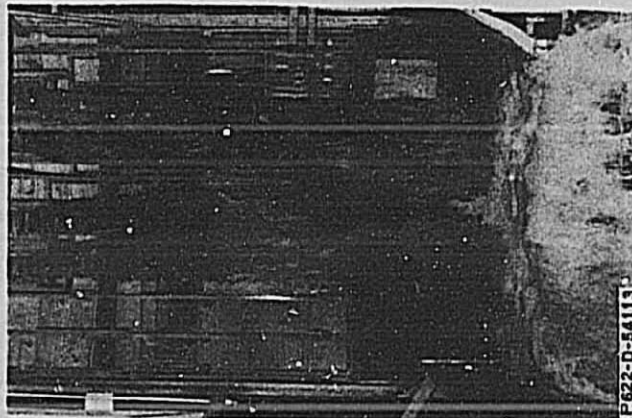
Stillling Basin Flow Conditions with
24-foot-wide Horizontal Baffle
on Upstream Face of Weir



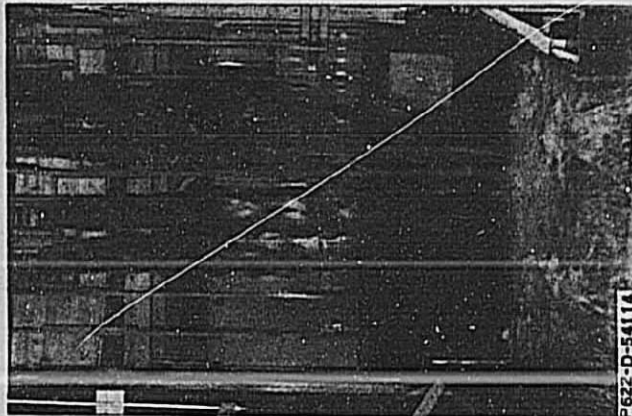
A. Res. Elev. 7165
Gates open 100%
 $Q = 40,000$ cfs



B. Res. Elev. 7160
Gates equally open
 $Q = 30,000$ cfs



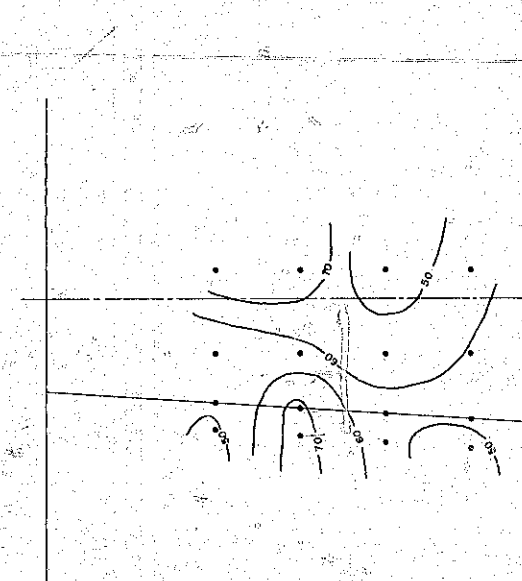
C. Res. Elev. 7160
Gates equally open
 $Q = 20,000$ cfs



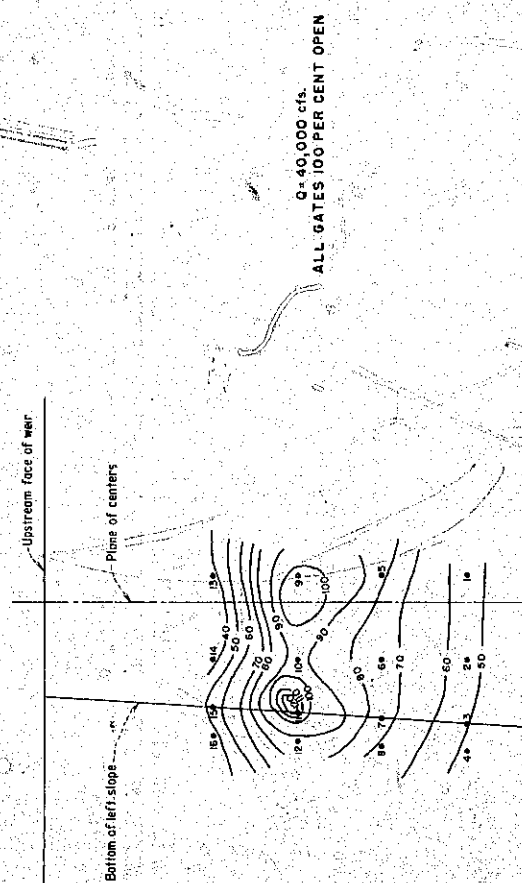
D. Res. Elev. 7160
Gates equally open
 $Q = 10,000$ cfs

MORROW POINT DAM SPILLWAY
1:24 Scale Model

Alternate Design
Flow Conditions with
Spillway Conduits Horizontal



PRESSURE CONTOURS ON STILLING BASIN FLOOR
WITH DEFLECTING HOODS ON INSIDE JETS



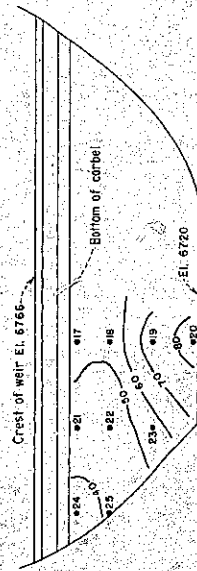
PRESSURE CONTOURS ON STILLING BASIN FLOOR
WITHOUT DEFLECTING HOODS ON INSIDE JETS



PRESSURE CONTOURS ON UPSTREAM FACE OF WEIR
WITH DEFLECTING HOODS ON INSIDE JETS



WEIR
CROSS - SECTION



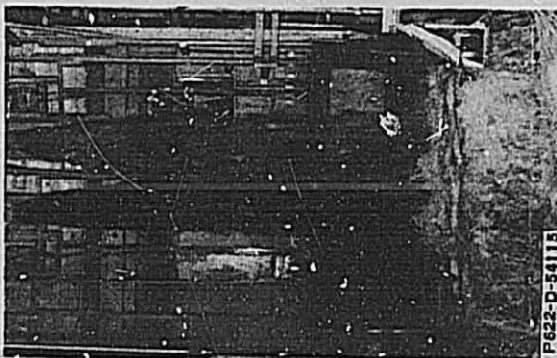
PRESSURE CONTOURS ON UPSTREAM FACE OF WEIR
WITHOUT DEFLECTING HOODS ON INSIDE JETS

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 SCALE MODEL
ALTERNATE DESIGN
MAXIMUM WATER MANOMETER PRESSURES
ON WEIR AND STILLING BASIN FLOOR

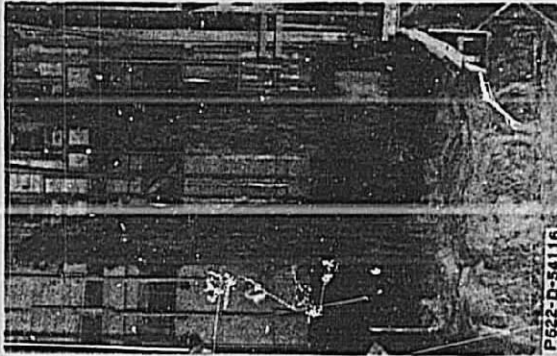
NOTES
*24 - Piezometer location
Pressures are referenced to piezometer opening
Pressures are in feet of water (prototype)



FIGURE 13
REPORT HYD-557



A. Res. Elev. 7160
Inside gates open 100%
 $Q = 20,000$ cfs

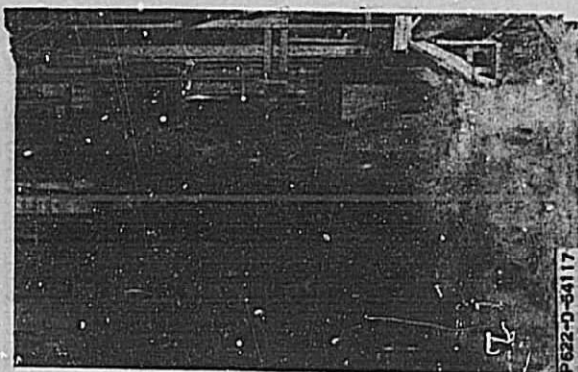


B. Res. Elev. 7160
Outside gates open 100%
 $Q = 20,000$ cfs

MORROW POINT DAM SPILLWAY
1:24 Scale Model

Alternate Design
Stilling Basin Flow Conditions
for Operation of Inside or
Outside Conduits Alone
Spillway Conduits Horizontal

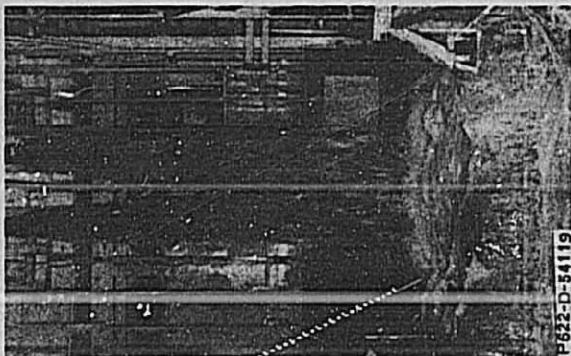
FIGURE 14
REPORT HYD-557



A. Res. Elev. 7165
Gates open 100%
 $Q = 39,600$ cfs



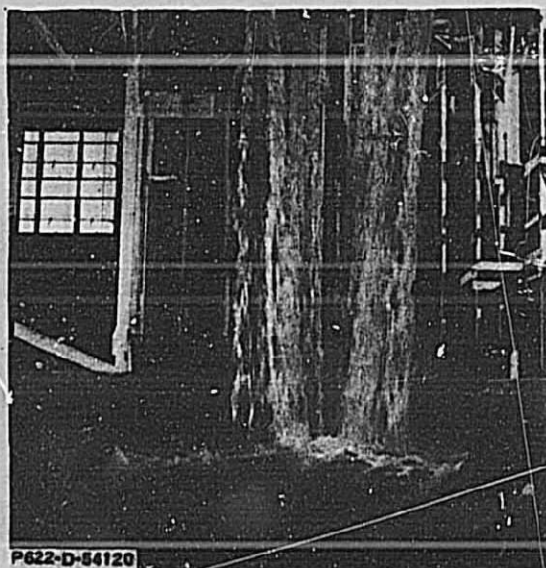
B. Res. Elev. 7160
Gates $\approx 50\%$ open
 $Q = 19,600$ cfs



C. Res. Elev. 7160
Inside gates open 100%
 $Q = 19,600$ cfs

MORROW POINT DAM SPILLWAY
1:24 Scale Model

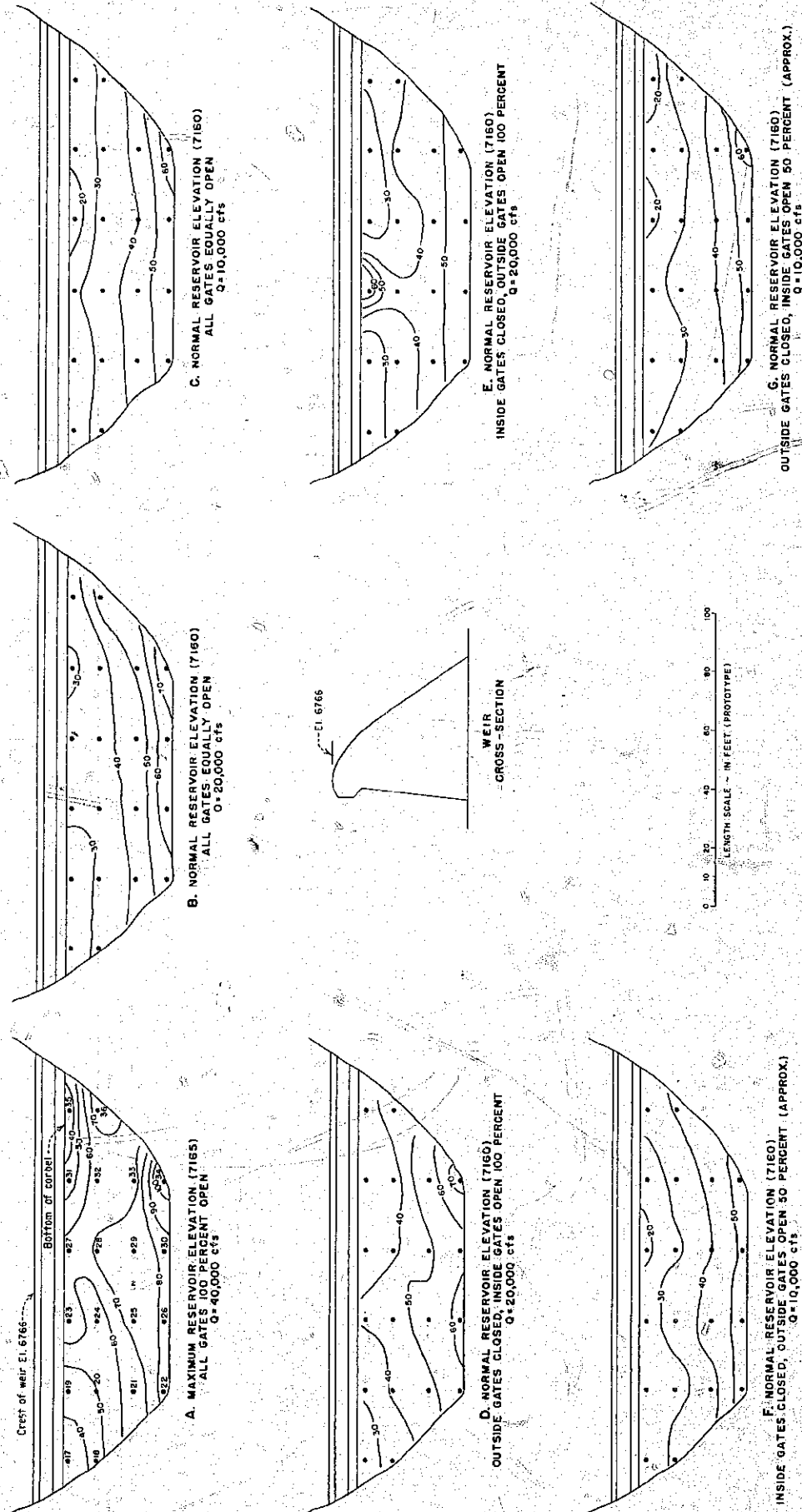
Alternate Design
Stilling Basin Flow Conditions with
Deflecting Hoods on
Inside Conduits



Res. Elev. 7165
Gates open 100%
 $Q = 40,000$ cfs

MORROW POINT DAM SPILLWAY
1:24 Scale Model

Alternate Design
Stilling Basin Flow Conditions with
Inside Conduits Tipped 27° Downward



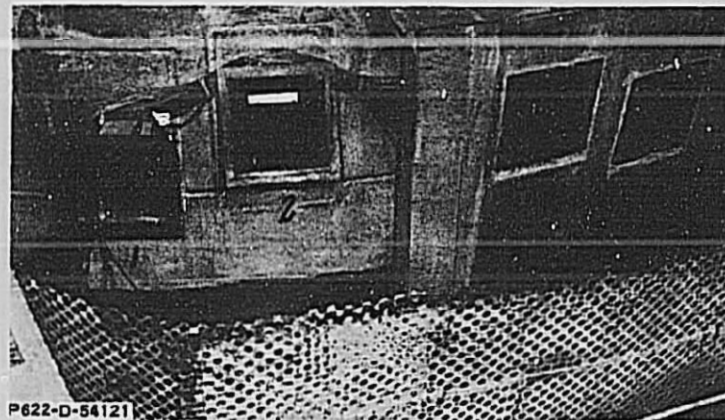
NOTES

- 17 piezometer location
Pressures are referenced to piezometer opening
Pressures are in feet (prototype) of water

**MORROW POINT DAM
SPILLWAY AND OUTLET WORKS**

1:24 SCALE MODEL
ALTERNATE DESIGN
INSIDE GATES TIPPED 37° DOWNWARD

MAXIMUM INSTANTANEOUS PRESSURES
ON UPSTREAM FACE OF WEIR



- 1 - Original configuration. All four conduits horizontal.
- 2 - First modification. Original bellmouth tipped 27° downward.
- 3 and 4 - Recommended configuration. No. 4 conduit horizontal with original bellmouth. No. 3 conduit tipped 27° downward with modified bellmouth. Upstream face of dam installed.

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Modifications to the Spillway Entrances

FIGURE 18
REPORT HYD-557

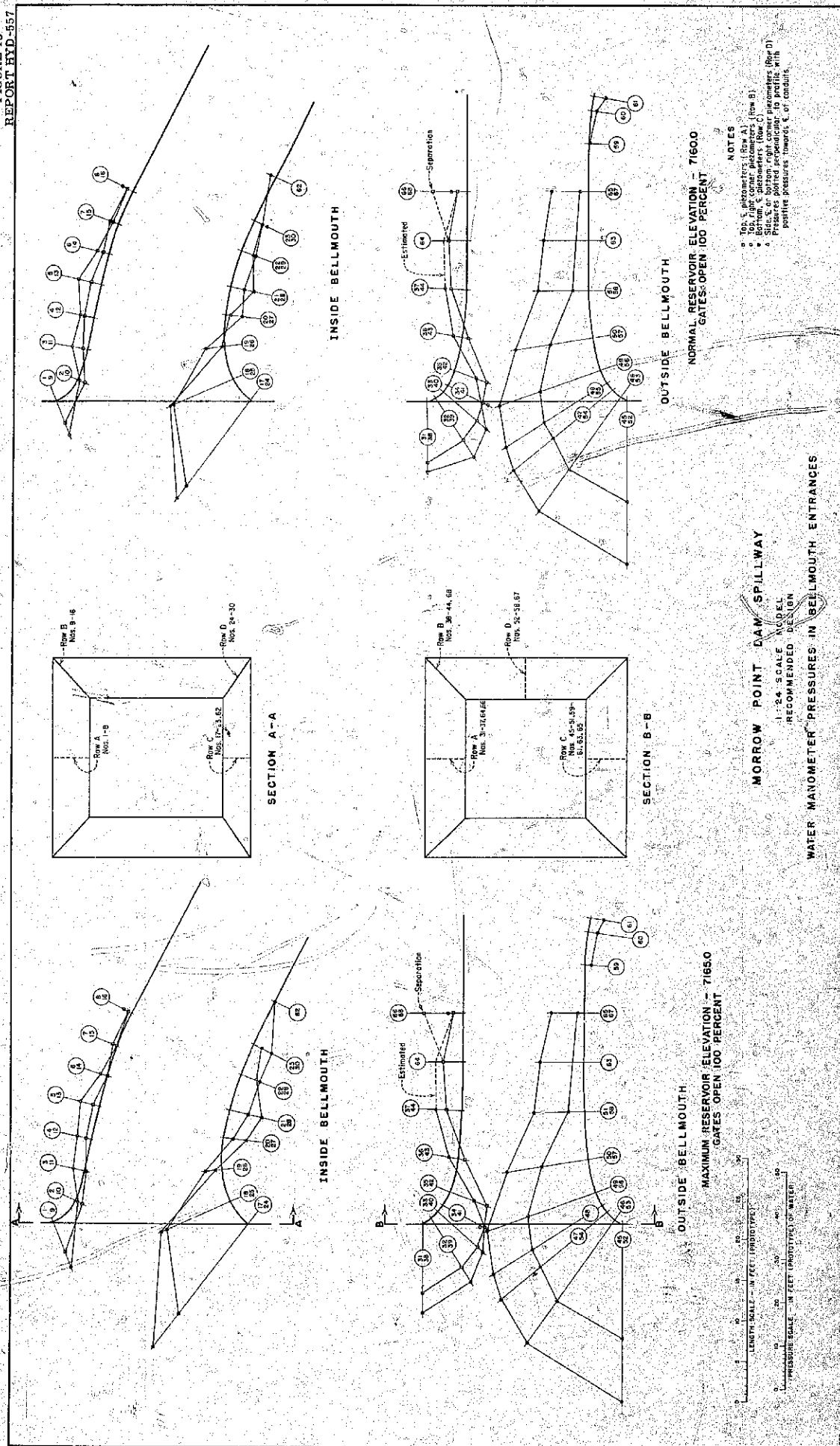


FIGURE 19
REPORT HYD-557



A. Spwy. $Q = 20,000$ cfs
O.W. $Q = 1,500$ cfs
P.P. $Q = 5,200$ cfs



B. Spwy. $Q = 40,000$ cfs
O.W. $Q = 1,500$ cfs
P.P. $Q = 5,200$ cfs

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Revised Alternate Design
Stilling Basin and Tailrace Flow Conditions

FIGURE 20
REPORT HYD-557

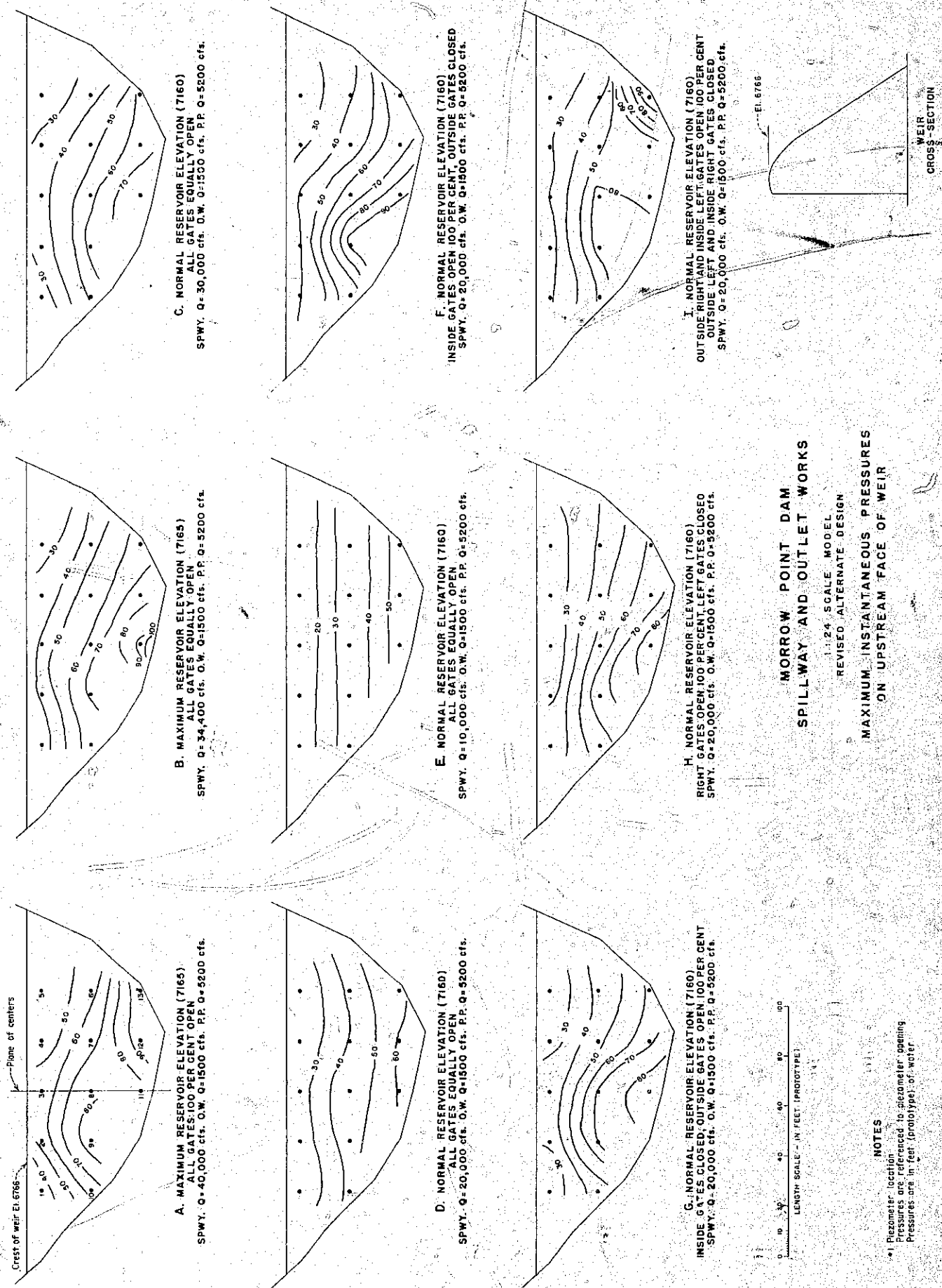


FIGURE 21
REPORT HYD-557

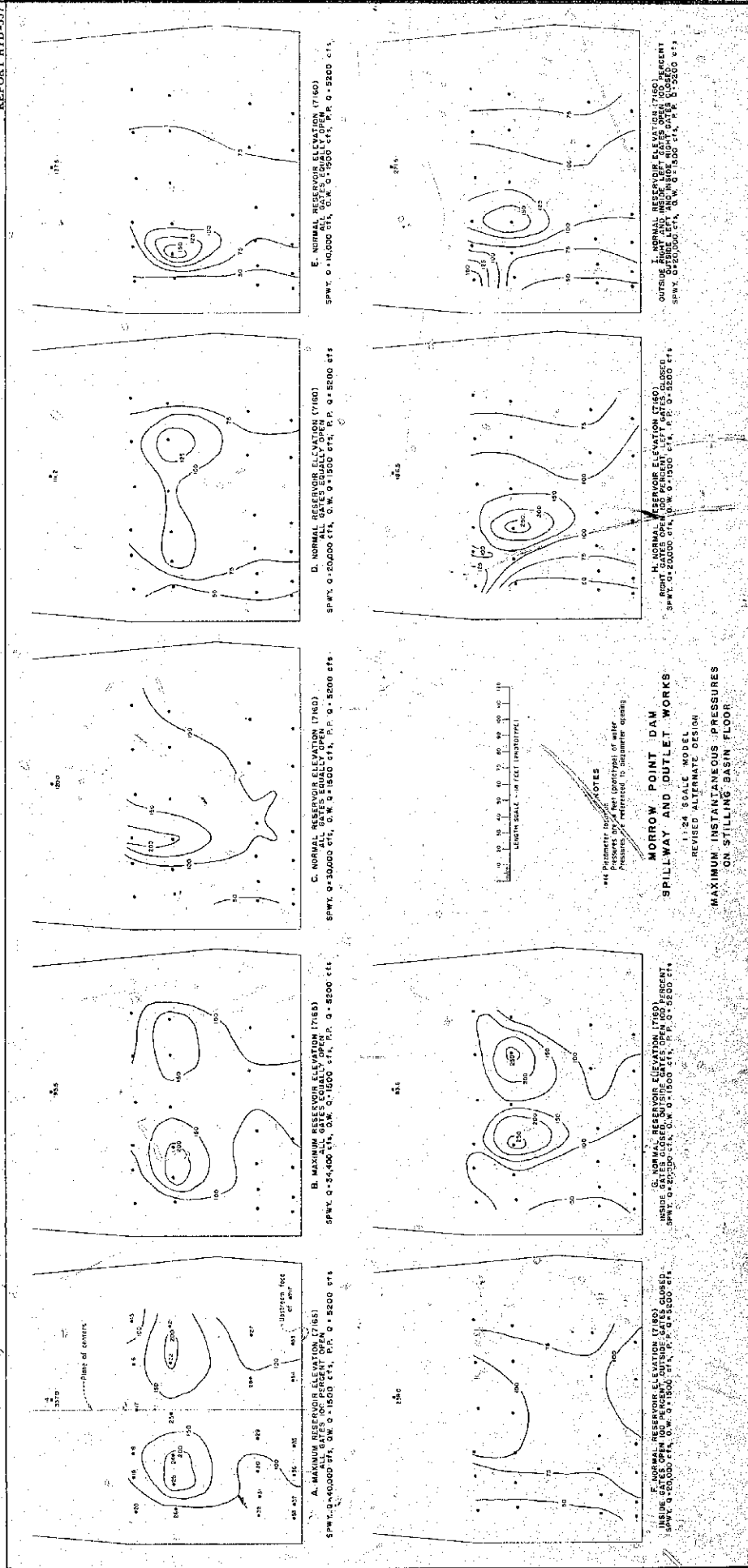
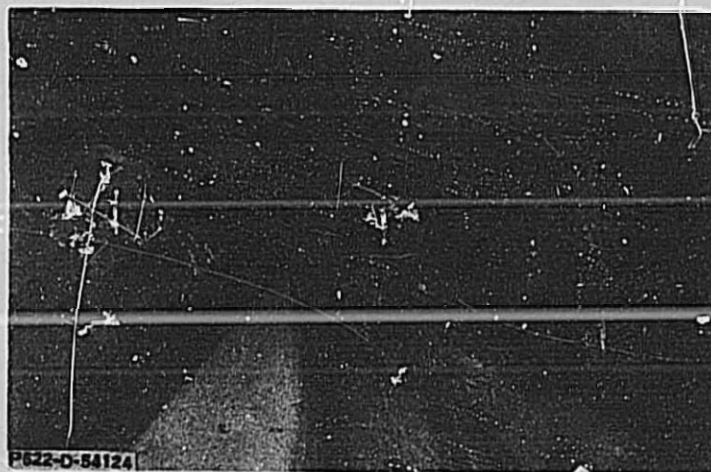
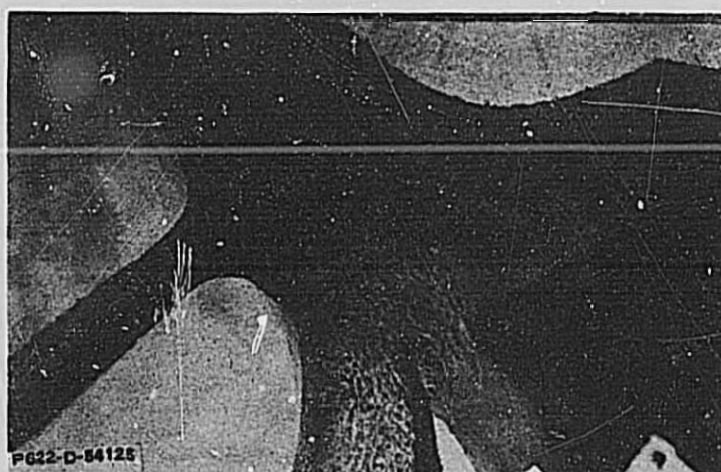


FIGURE 22
REPORT HYD-557



A. Before streamlining



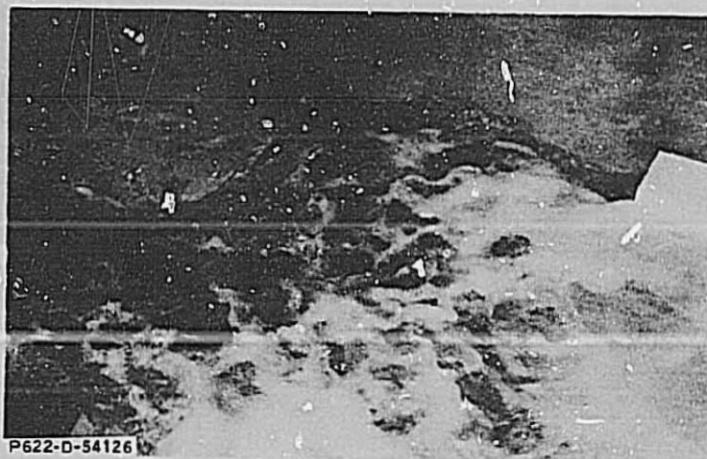
B. After streamlining

Powerplant Discharge = 5,200 cfs

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Revised Alternate Design
Tailrace Topography Before
and After Streamlining

FIGURE 23
REPORT HYD-557



A. Spwy. $Q = 20,000$ cfs
O.W. $Q = 1,500$ cfs
P.P. $Q = 5,200$ cfs



B. Spwy. $Q = 40,000$ cfs
O.W. $Q = 1,500$ cfs
P.P. $Q = 5,200$ cfs

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Revised Alternate Design
Flow Constriction Immediately
Downstream from Weir

FIGURE 24
REPORT HYD-557



MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Revised Alternate Design
Excavated Right Channel Bank
Spwy. $Q = 8,600$ cfs, O.W. $Q = 1,500$ cfs,
P.P. $Q = 5,200$ cfs

FIGURE 25
REPORT HYD-557



MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Revised Alternate Design
Excavated Right Channel Bank
Spwy. $Q = 17,200$ cfs, O.W. $Q = 1,500$ cfs,
P.P. $Q = 5,200$ cfs

FIGURE 26
REPORT HYD-557



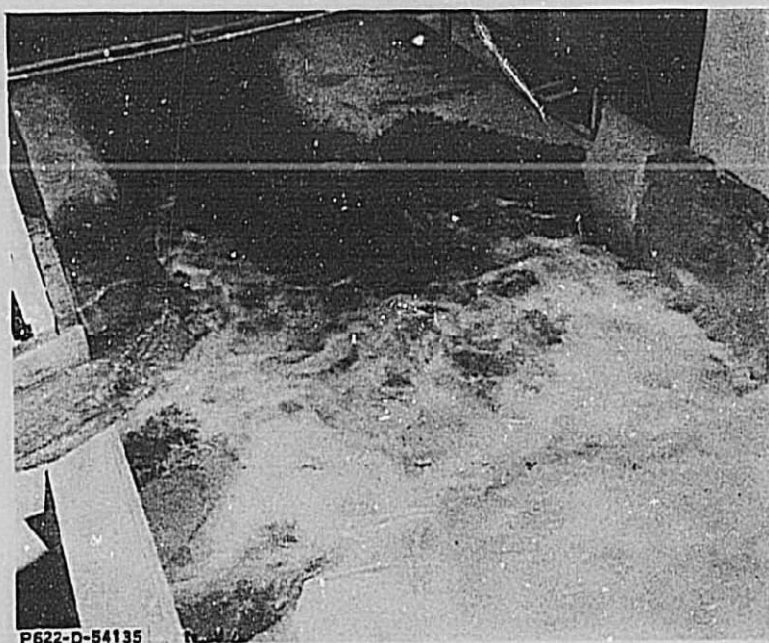
P622-D-54132



P622-D-54133

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

FIGURE 27
REPORT HYD-557



MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Revised Alternate Design
Excavated Right Channel Bank
Spwy. $Q = 34,400$ cfs, O. W. $Q = 1,500$ cfs,
P.P. $Q = 5,200$ cfs

FIGURE 28
REPORT HYD-557



Looking upstream.

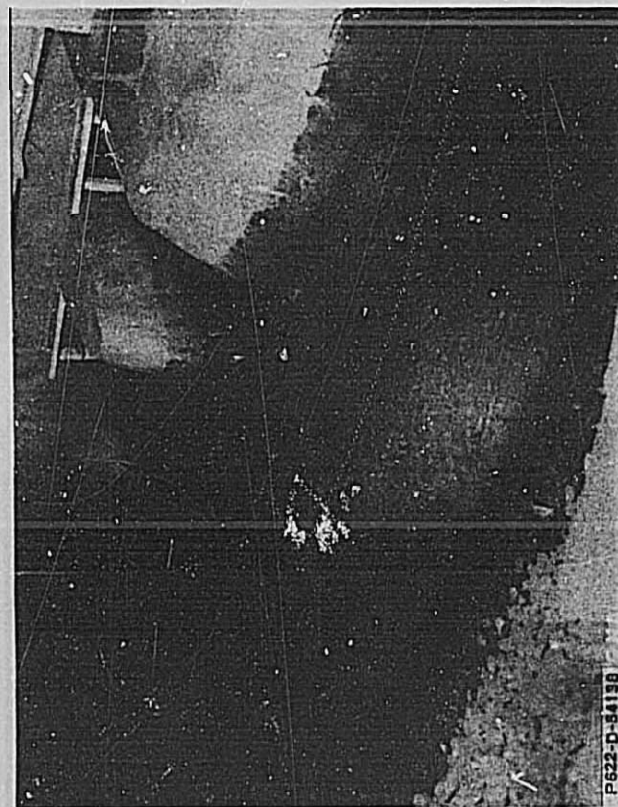


Looking downstream.

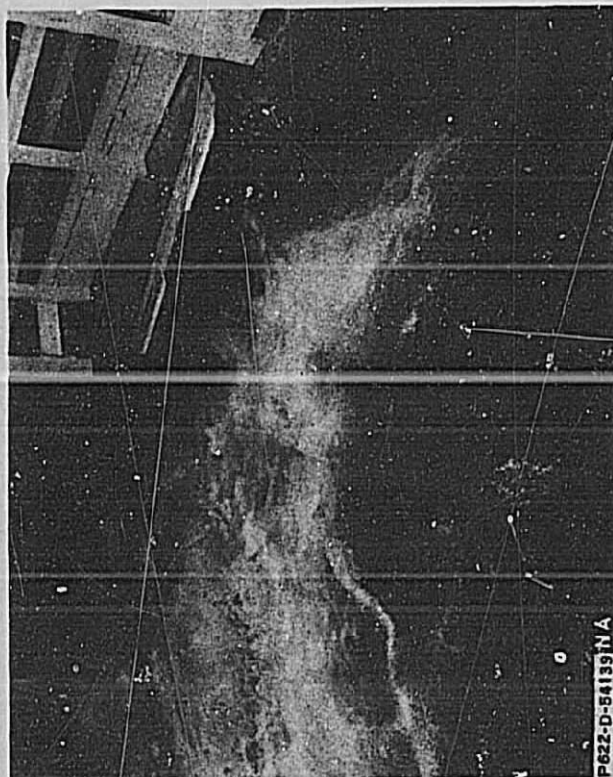
MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Recommended Design
Removal of Weir Piers and
Extension of Stilling Basin Lining

FIGURE 29
REPORT HYD-557



A. Powerplant $Q = 5,200$ cfs



B. Spwy. $Q = 34,400$ cfs
O.W. $Q = 1,500$ cfs
P.P. $Q = 5,200$ cfs

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Recommended Design
Tailrace Flow Conditions with
Revised Weir Topography

FIGURE 30
REPORT HYD-557



Spwy. $Q = 8,600$ cfs
O. W. $Q = 1,500$ cfs
P. P. $Q = 5,200$ cfs



Spwy. $Q = 34,400$ cfs
O. W. $Q = 1,500$ cfs
P. P. $Q = 5,200$ cfs

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Recommended Design
Stilling Basin Flow Conditions
with Revised Weir
Topography

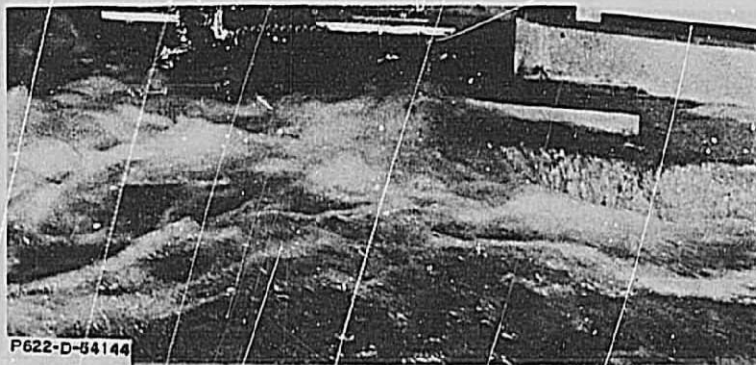
E 31
HYD-557



Spwy. $Q = 26,000$ cfs



Spwy. $Q = 31,000$ cfs



Spwy. $Q = 32,900$ cfs

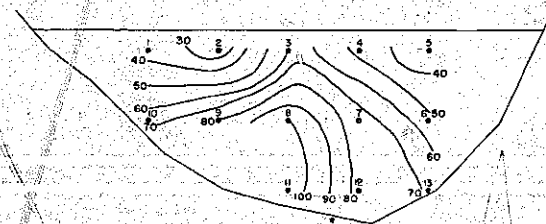
**MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model**

Recommended Design

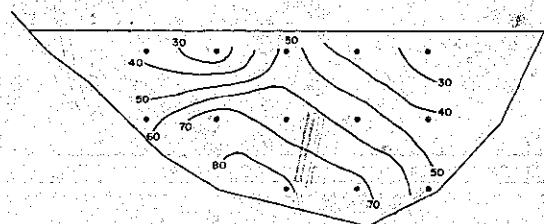
Flood Wall Tests

O. W. $Q = 1,500$ cfs

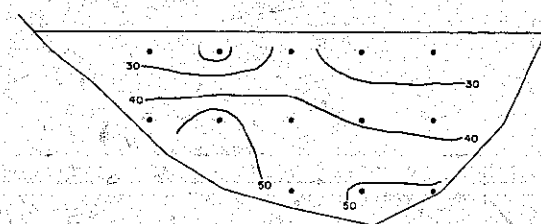
P. P. $Q = 5,200$ cfs



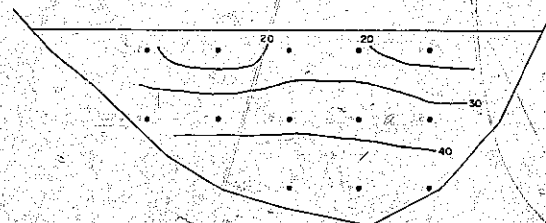
A. MAXIMUM RESERVOIR ELEVATION (7165)
ALL GATES 100 PERCENT OPEN
SPWY. Q = 40,000 cfs



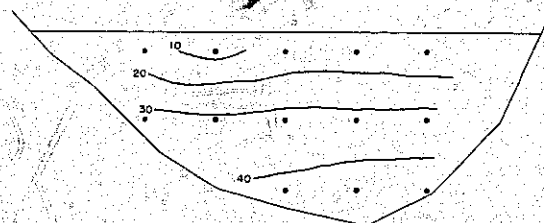
B. MAXIMUM RESERVOIR ELEVATION (7165)
ALL GATES EQUALLY OPEN
SPWY. Q = 34,400 cfs



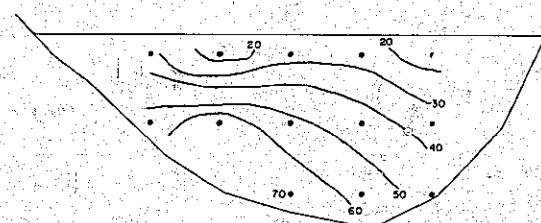
C. NORMAL RESERVOIR ELEVATION (7160)
ALL GATES EQUALLY OPEN
SPWY. Q = 25,800 cfs



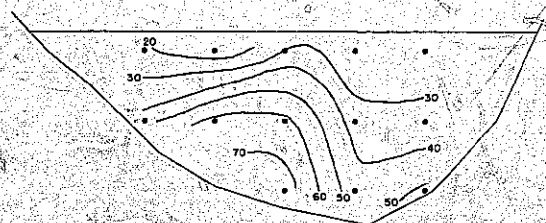
D. NORMAL RESERVOIR ELEVATION (7160)
ALL GATES EQUALLY OPEN
SPWY. Q = 17,200 cfs



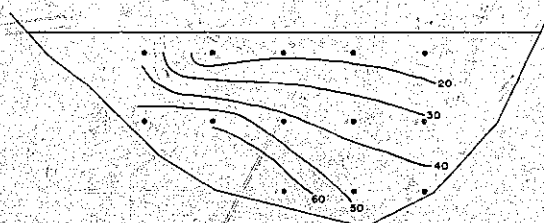
E. NORMAL RESERVOIR ELEVATION (7160)
ALL GATES EQUALLY OPEN
SPWY. Q = 8,600 cfs



F. NORMAL RESERVOIR ELEVATION (7160)
INSIDE GATES OPEN, OUTSIDE GATES CLOSED
SPWY. Q = 17,200 cfs



G. NORMAL RESERVOIR ELEVATION (7160)
OUTSIDE GATES OPEN, INSIDE GATES CLOSED
SPWY. Q = 17,200 cfs



H. NORMAL RESERVOIR ELEVATION (7160)
RIGHT GATES OPEN, LEFT GATES CLOSED
SPWY. Q = 17,200 cfs



I. NORMAL RESERVOIR ELEVATION (7160)
RIGHT OUTSIDE AND LEFT INSIDE GATES OPEN 100 PERCENT
SPWY. Q = 17,200 cfs

0 20 40 60 80 100
LENGTH SCALE - IN FEET (PROTOTYPE)

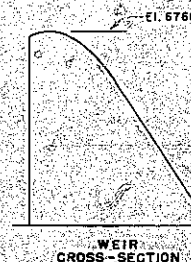
NOTES

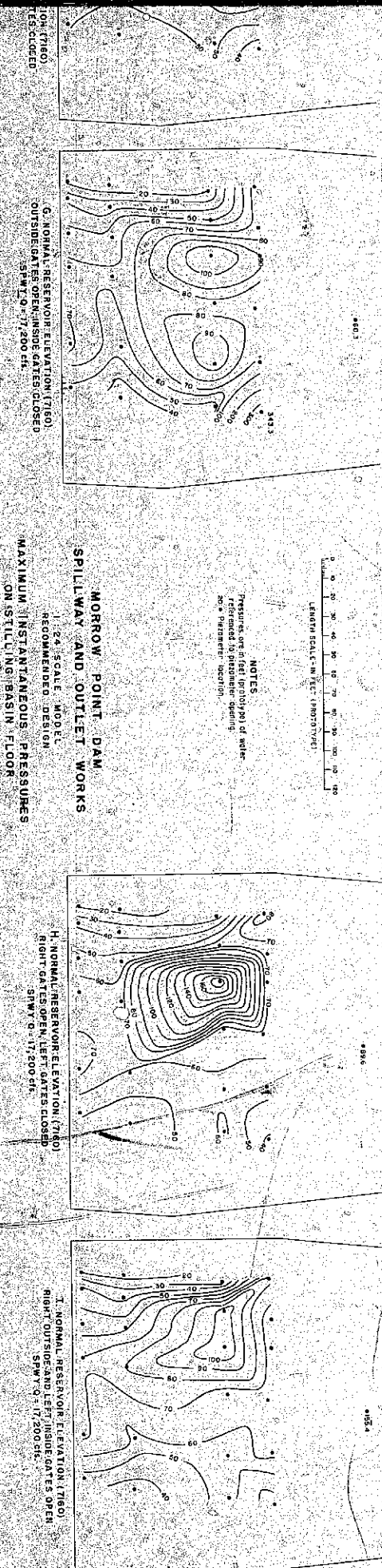
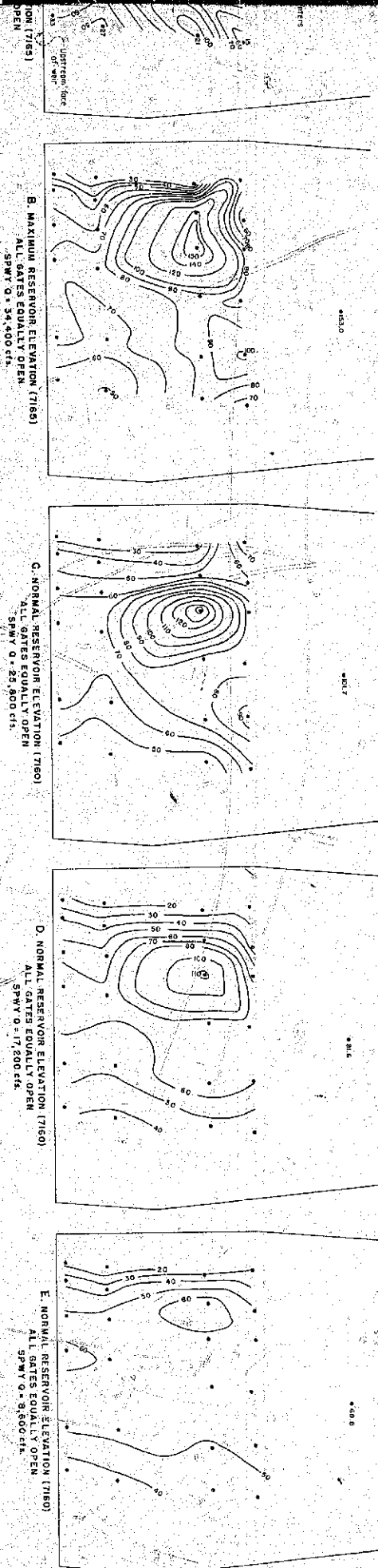
- Piezometer location
- Pressures are referenced to piezometer opening
- Pressures are in feet (prototype) of water

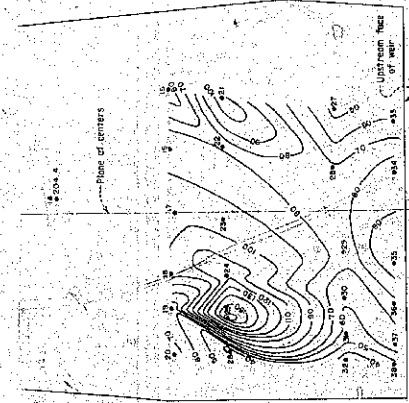
MORROW POINT DAM SPILLWAY AND OUTLET WORKS

1/24 SCALE MODEL
RECOMMENDED DESIGN

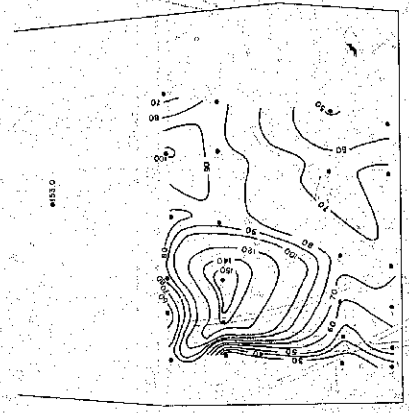
MAXIMUM INSTANTANEOUS PRESSURES
ON UPSTREAM FACE OF WEIR



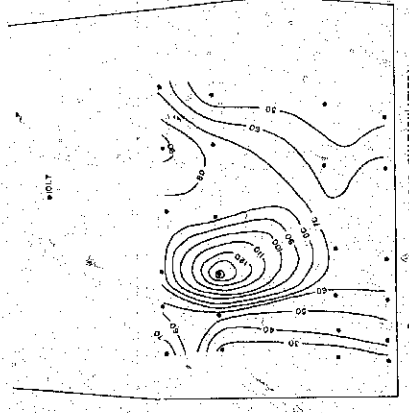




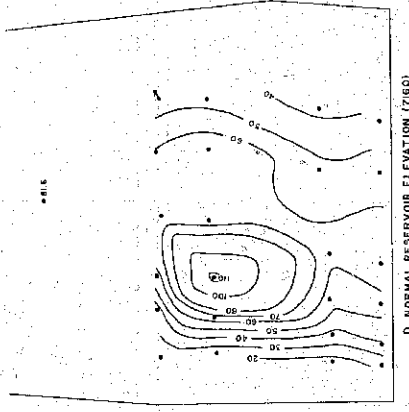
A. MAXIMUM RESERVOIR ELEVATION (7165)
ALL GATES 100 PER CENT OPEN
SPWY Q = 40,000 cfs.



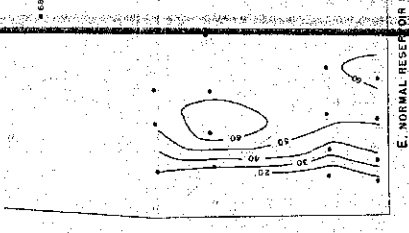
B. MAXIMUM RESERVOIR ELEVATION (7165)
ALL GATES EQUALLY OPEN
SPWY Q = 34,400 cfs.



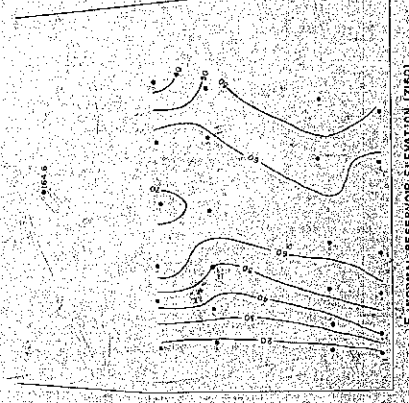
C. NORMAL RESERVOIR ELEVATION (7180)
ALL GATES EQUALLY OPEN
SPWY Q = 25,800 cfs.



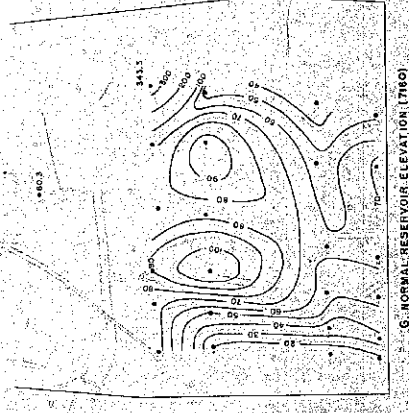
D. NORMAL RESERVOIR ELEVATION (7160)
ALL GATES EQUALLY OPEN
SPWY Q = 17,200 cfs.



E. NORMAL RESERVOIR
ALL GATES EQUALLY OPEN
SPWY Q = 17,200 cfs.



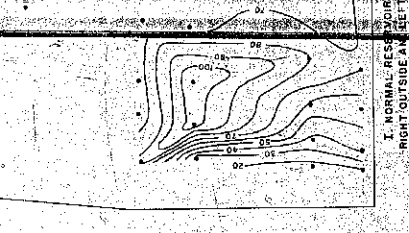
F. NORMAL RESERVOIR ELEVATION (7160)
INSIDE GATES OPEN, OUTSIDE GATES CLOSED
SPWY Q = 17,200 cfs.



G. NORMAL RESERVOIR ELEVATION (7160)
OUTSIDE GATES OPEN, INSIDE GATES CLOSED
SPWY Q = 17,200 cfs.



H. NORMAL RESERVOIR ELEVATION (7160)
RIGHT GATES OPEN, LEFT GATES CLOSED
SPWY Q = 17,200 cfs.

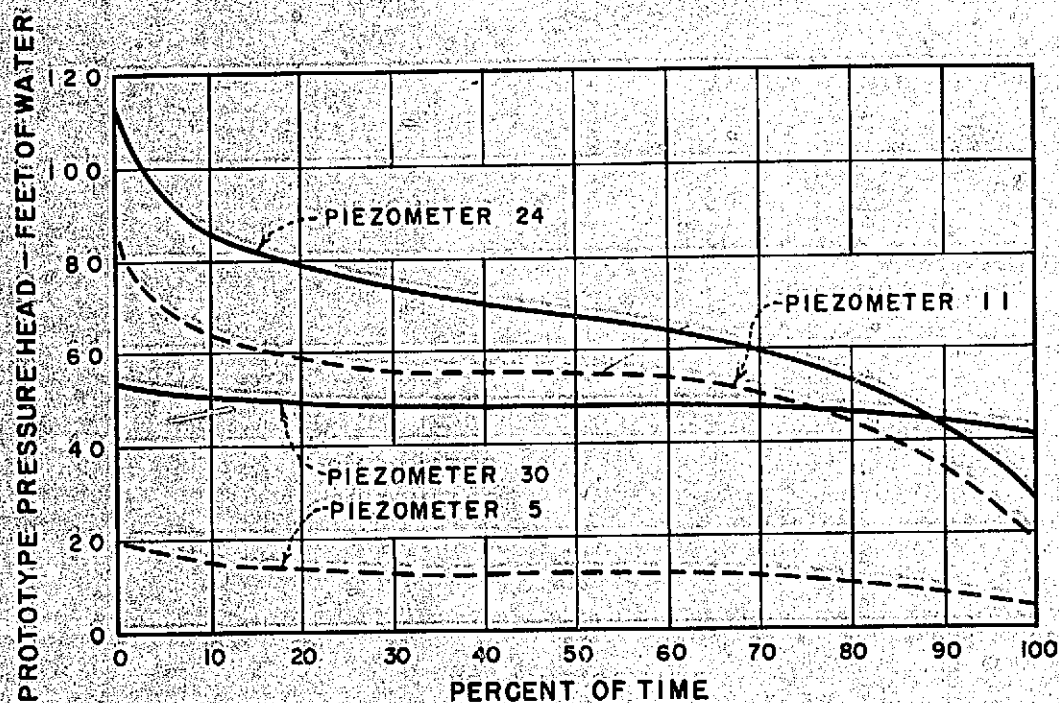


I. NORMAL RESERVOIR
RIGHT GATES OPEN, LEFT GATES CLOSED
SPWY Q = 17,200 cfs.

LENGTH SCALE - IN FEET (PHOTOGRAPH)

NOTES
Specimens are first prototypes of water
referenced to determine design
as a preliminary location

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1/24 SCALE MODEL
RECOMMENDED DESIGN
MAXIMUM INSTANTANEOUS PRESSURES
ON STILLING BASIN FLOOR



EXPLANATION

--- Weir piezometers
 — Floor piezometers

NOTES

Data for operation with outside gates 100 percent open, inside gates closed.

Pressures measured above piezometer openings.

Spillway discharge = 17,200 cfs.

MORROW POINT DAM SPILLWAY AND OUTLET WORKS

1:24 SCALE MODEL
 RECOMMENDED DESIGN

FREQUENCY DISTRIBUTION OF IMPACT PRESSURES ON
 STILLING BASIN FLOOR AND WEIR

FIGURE 34
 REPORT HYD-557



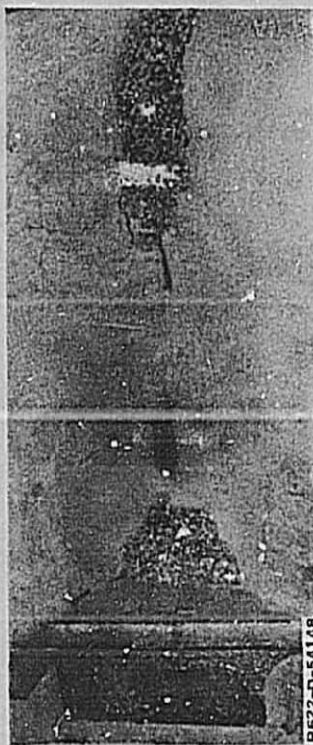
A. Stilling pool prior to test.



C. After 1 hour at spillway
 $Q = 17,200$ cfs



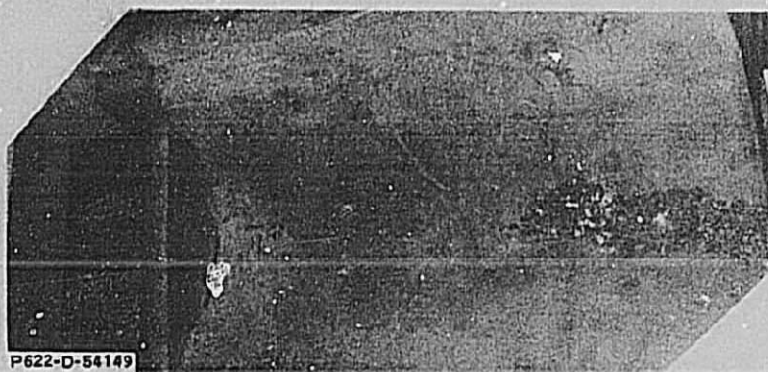
B. After 1 hour at spillway
 $Q = 8,600$ cfs



D. After 1 hour at spillway
 $Q = 25,800$ cfs

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Recommended Design
Movement of Material in
Stilling Basin
All Gates Equally Open



A. After 1 hour at spillway
 $Q = 34,400$ cfs

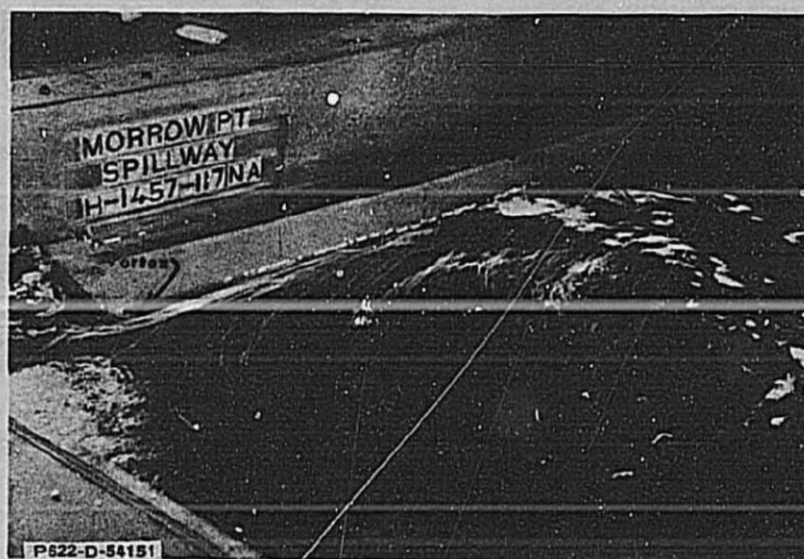


B. After 1 hour at spillway
 $Q = 34,400$ cfs

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Recommended Design
Movement of Material in
Stilling Basin
All Gates Equally Open

FIGURE 37
REPORT HYD-557



A. Spillway $Q = 40,000$ cfs, gates 100% open, reservoir at elevation 7165.



B. Spillway $Q = 25,800$ cfs, reservoir at elevation 7160.

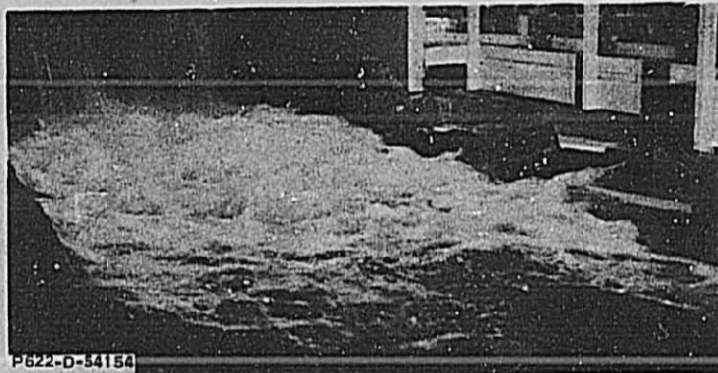
MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Recommended Design
Reservoir Flow Patterns

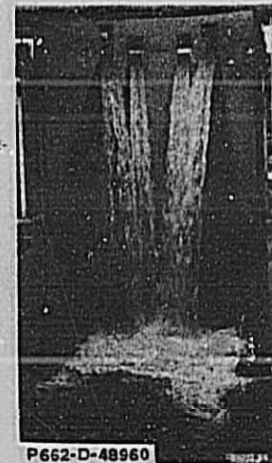
FIGURE 38
REPORT HYD-557



A. Spwy. $Q = 40,000$ cfs
O.W. $Q = 1,500$ cfs
P.P. $Q = 5,200$ cfs



B. Spwy. $Q = 34,400$ cfs
O.W. $Q = 1,500$ cfs
P.P. $Q = 5,200$ cfs



C. Spwy. $Q = 25,800$ cfs
O.W. $Q = 1,500$ cfs
P.P. $Q = 5,200$ cfs



MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Recommended Design
Symmetrical Spillway Operation

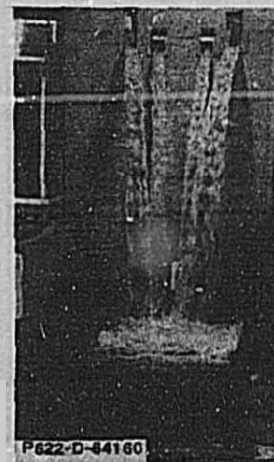
FIGURE 39
REPORT HYD-557



A. Spwy. $Q = 17,200$ cfs
O. W. $Q = 1,500$ cfs
P. P. $Q = 5,200$ cfs



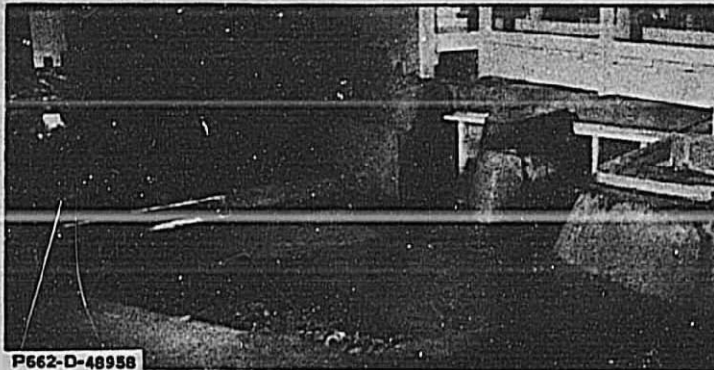
B. Spwy. $Q = 8,600$ cfs
O. W. $Q = 1,500$ cfs
P. P. $Q = 5,200$ cfs



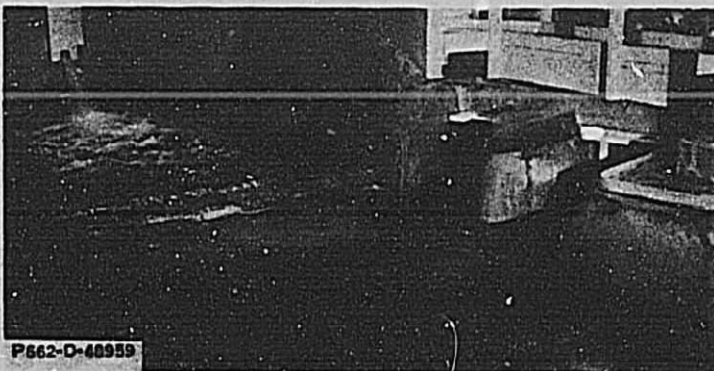
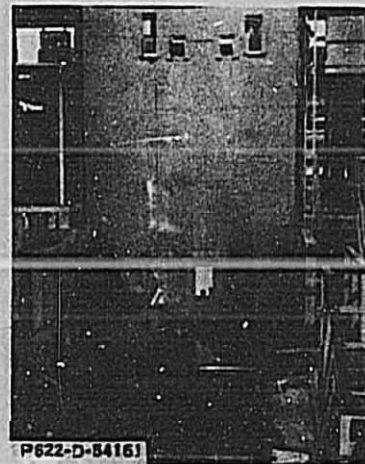
MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Recommended Design
Symmetrical Spillway Operation

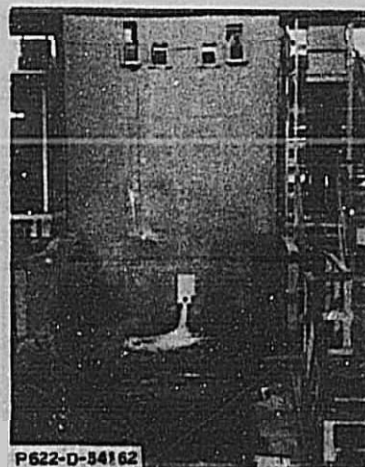
FIGURE 40.
REPORT HYD-557



A. Powerplant $Q = 5,200$ cfs



B. Outlet works $Q = 1,500$ cfs
Powerplant $Q = 5,200$ cfs



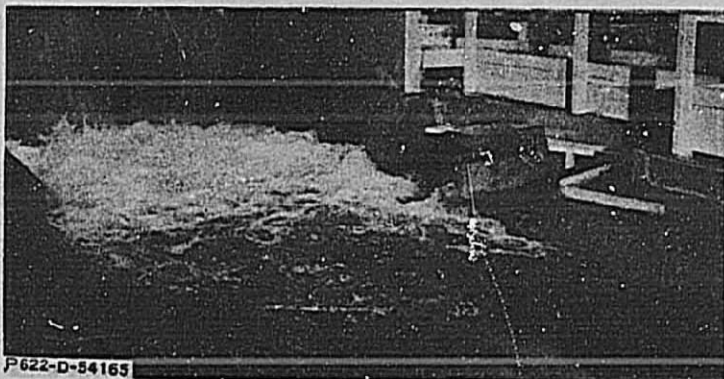
MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Recommended Design
Powerplant Operating Alone, and
Outlet Works and Powerplant Operating

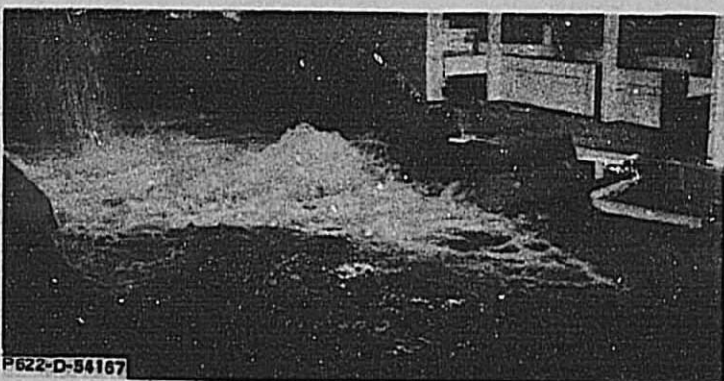
FIGURE 41
REPORT HYD-557



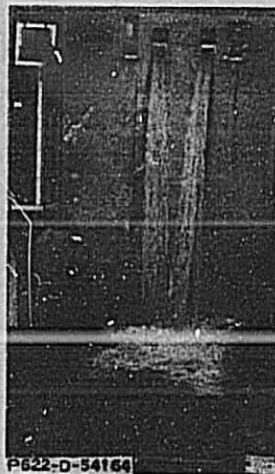
P622-D-54163



P622-D-54165



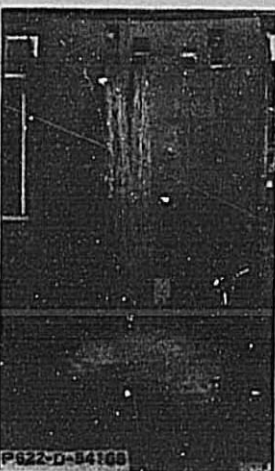
P622-D-54167



P622-D-54164



P622-D-54166



P622-D-54168

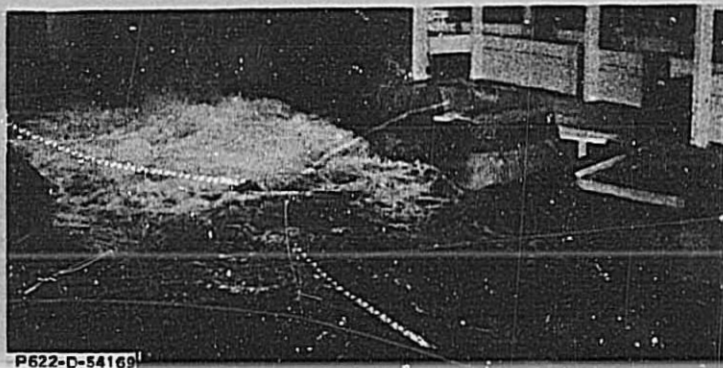
Spwy. $Q = 17,200$ cfs
O.W. $Q = 1,500$ cfs
P.P. $Q = 5,200$ cfs

All photos

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Recommended Design
Symmetrical and Asymmetrical Spillway Operation

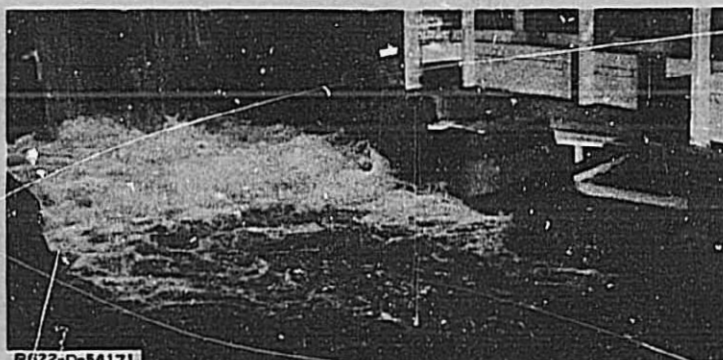
FIGURE 42
REPORT HYD-557



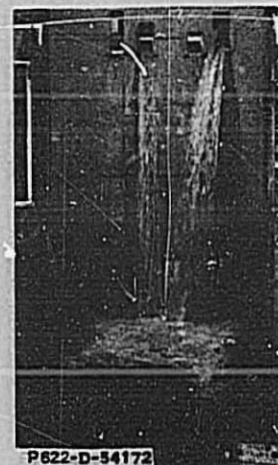
P622-D-54169



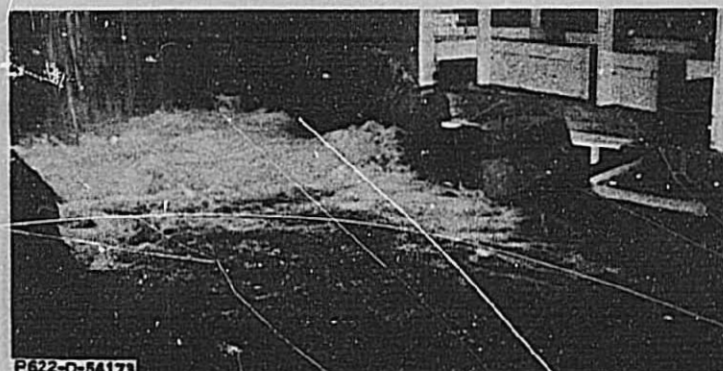
P622-D-54170



P622-D-54171



P622-D-54172



P622-D-54173



P622-D-54174

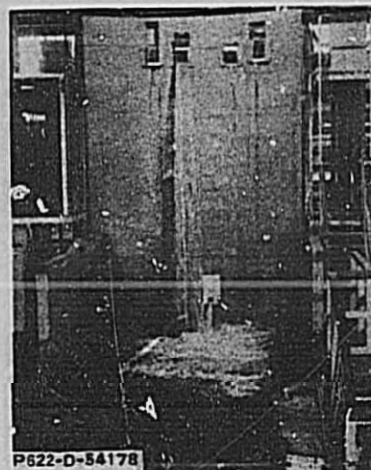
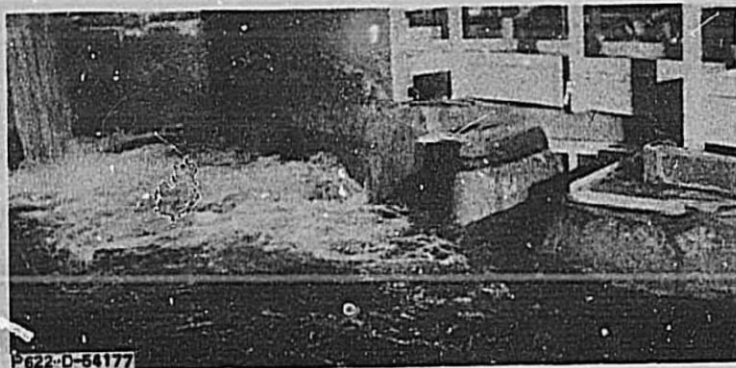
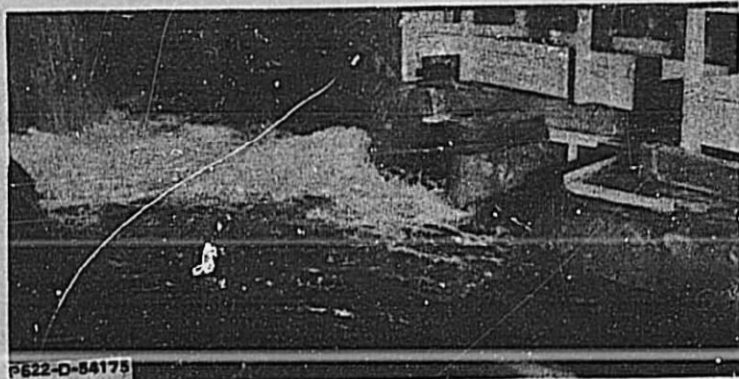
Spwy. $Q = 17,200$ cfs
O. W. $Q = 1,500$ cfs
P. P. $Q = 5,200$ cfs

All photos

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Recommended Design
Asymmetrical Spillway Operation

FIGURE 43
REPORT HYD-557



Spwy. $Q = 8,600$ cfs
O. W. $Q = 1,500$ cfs
P. P. $Q = 5,200$ cfs

All photos

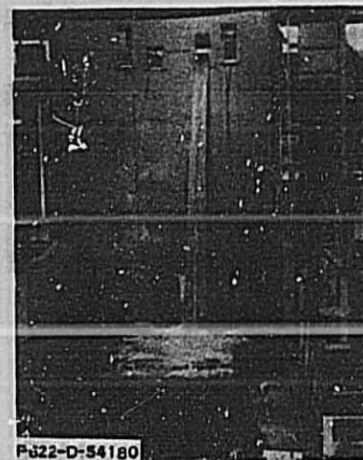
MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Recommended Design
Asymmetrical Spillway Operation

FIGURE 44
REPORT HYD-557



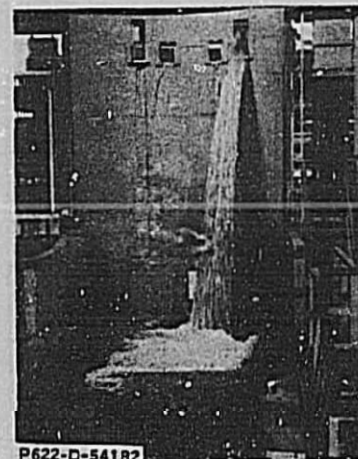
P622-D-54179



P622-D-54180



P622-D-54181



P622-D-54182

Spwy. $Q = 8,600$ cfs
O. W. $Q = 1,500$ cfs
P. P. $Q = 5,200$ cfs

All photos

MORROW POINT DAM
SPILLWAY AND OUTLET WORKS
1:24 Scale Model

Recommended Design
Asymmetrical Spillway Operation

CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MESA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
LENGTH		
Mil.	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
Feet	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters
Feet	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
Miles (statute)	1.609344 (exactly)	Kilometers
AREA		
Square inches	6.4516 (exactly)	Square centimeters
Square feet	929.03 (exactly)*	Square centimeters
Square feet	0.092903 (exactly)	Square meters
Square yards	0.836127	Square meters
Acres	0.404699	Hectares
Acres	4,046.9*	Square meters
Acres	0.0040469*	Square kilometers
Square miles	2.58999	Square kilometers
VOLUME		
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
CAPACITY		
Fluid ounces (U.S.)	29.5737	Cubic centimeters
Fluid ounces (U.S.)	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
Liquid pints (U.S.)	0.473166	Liters
Quarts (U.S.)	9.46358	Cubic centimeters
Quarts (U.S.)	0.946358	Liters
Gallons (U.S.)	3.78543*	Cubic centimeters
Gallons (U.S.)	3.78543	Cubic decimeters
Gallons (U.S.)	3.78533	Liters
Gallons (U.S.)	0.00378543*	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
Gallons (U.K.)	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	764.55*	Liters
Acres-feet	1,233.5*	Cubic meters
Acres-feet	1,233,500*	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avo)	28.3495	Grams
Pounds (avo)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
Long tons (2,240 lb)	0.907185	Metric tons
	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
Pounds per square foot	0.689476	Kilograms per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newton's per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
Pounds per cubic foot	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Pounds per gallon (U.S.)	6.2262	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.S.)	99.779	Grams per liter
PENDING MOMENT OR TORQUE		
Foot-pounds	0.013251	Meter-kilograms
Foot-pounds	1.19495 x 10 ⁶	Centimeter-grams
Foot-pounds	0.138255	Meter-kilograms
Foot-pounds per inch	1.35582 x 10 ⁷	Centimeter-grams
Foot-pounds per inch	5.4431	Centimeter-kilograms
Foot-pounds per inch	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
Feet per second	0.3048 (exactly)	Meters per second
Miles per hour	0.965873 x 10 ⁻³	Centimeters per second
Miles per hour	1.60934 (exactly)	Kilometers per hour
Miles per hour	0.44704 (exactly)	Meters per second
ACCELERATIONS		
Feet per second ²	0.3048	Meters per second ²
FLOW		
Cubic feet per second (second-foot)	0.028317	Cubic meters per second
Cubic feet per minute	0.07719	Liters per second
Gallons (U.S.) per minute	0.05909	Liters per second

Multiply	By	To obtain
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newton's
	4.4482 x 10 ⁻³ *	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
Btu per pound	1,055.06	Joules
Foot-pounds	1.35582*	Joules
		Joules per gram
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft ² deg F (1, thermal conductivity)	1.442	Milliwatts/cm deg C
Btu ft/hr ft ² deg F	0.1240	Kg cal/hr m deg C
Btu/hr ft ² deg F (C, thermal conductivity)	1.4880*	Kg cal m/hr m ² deg C
Deg F hr ft ² /Btu (R, thermal resistance)	0.568	Milliwatts/cm ² deg C
Btu/hr ft ² deg F (C, thermal resistance)	4.852	Kg cal/hr m ² deg C
Btu/lb deg F (C, heat capacity)	1.761	Deg C cal ² /milliwatt
ft ² /hr (thermal diffusivity)	1.050*	Deg C/gram deg C
	0.243	Cal/gram deg C
	0.07290*	Cal/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft ² (water vapor transmission)	16.7	Grams/24 hr m ²
P perms (permance)	0.659	Metric perms
Pere-inches (permeability)	1.67	Metric perms-centimeters

Multiply	By	To obtain
OTHER QUANTITIES AND UNITS		
Cubic feet per square foot per day (seepage)	304.8*	Liters per square meter per day
Pound-second per square foot (viscosity)	4.852*	Kilogram second per square meter
Square feet per second (viscosity)	0.0290*	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Voile per mil	0.0254	Millimeters per millimeter
Lines per square foot (foot-candles)	10.764	Lumens per square meter
One-circular mils per foot	0.001663	One-square millimeter per meter
Milliamps per cubic foot	35.3147*	Milliamps per cubic meter
Milliamps per square foot	10.7639*	Milliamps per square meter
Gallons per square yard	4.57219*	Liters per square meter
Pounds per inch	0.47828*	Kilograms per centimeter

ABSTRACT

The preliminary design of an overflow spillway at the crest of the dam and a slide-gate-controlled outlet works near the dam base was abandoned because of undesirable flow conditions in the stilling basin resulting from high velocity efflux from the outlet works. An alternate design, consisting of four fixed-wheel gate-controlled outlets near the dam crest and a small outlet works near the base, was recommended following several modifications. A 1:24 scale model was used in developing the design of the spillway and to determine the hydraulic operating characteristics of the recommended freefall orifice-type spillway, slide-gate controlled outlet works, and tailrace channels of the underground powerplant. Comprehensive data were obtained concerning pressure distribution in the spillway conduits and bellmouth entrances, on the stilling basin floor, and on the stilling basin weir. Minor modifications were made to the topography in the tailrace area to improve flow conditions during large spillway discharges. The stability of riprap protection was determined, and tests were made concerning movement of material in the stilling pool. Operating characteristics of all features of the recommended design were observed.

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DESCRIPTORS-- *arch dams/ *spillways/ *outlet works/ *free fall/ *model tests/ hydraulic models/ manometers/ orifices/ tailrace/ water pressures/ weirs/ instrumentation/ piezometers/ pressure measuring equip/ discharges/ underground powerplants/ fixed wheel gates/ slide gates/ impact/ energy dissipation/ riprap/ research and development IDENTIFIERS-- *bellmouths/ Morrow Point Dam, Colorado/ Curecanti Unit, Colorado/ Colorado River Storage Project/ Colorado

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